Proceedings of the National Ocean Survey

Hydrographic Survey Conference

January 7-11, 1980
Gaithersburg, Maryland

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

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Seventh Annual Meeting

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U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
National Ocean Survey
Rear Admiral H. R. Lippold, Jr., Director

PREFACE

This Seventh Annual National Ocean Survey (NOS) Hydrographic Survey Conference was distinguished by the participation of the U.S. Navy Oceanographic Office, the Defense Mapping Agency, and the Canadian Hydrographic Service. Communication of ideas and discussion of problems have been objectives of this conference from its inception. The interchange of information with representatives of these other surveying and mapping agencies contributed greatly to meeting these objectives, and, we hope, will warrant the continuation of their association with the conference in the future. Information contained in these proceedings is in the public domain. The views presented do not necessarily reflect the policy of NOS.

Special acknowledgment is due to Janet Springsteen and Betty O'Dell for their editorial work on the papers, and the following secretaries and typists for the final product: Ruth Carcaterra, Cheryl Dabney, James Davis, Kathleen Flynn, Sally Furukawa, Marie Gardella, Tim McCarthy, Paula McConville, Lily Noguchi, and Toshiko Ota.

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OPENING REMARKS

R. Adm. H. R. Lippold, Jr.
Director
National Ocean Survey
Rockville, MD 20852

Good Morning! Welcome to the Seventh Annual National Ocean Survey Hydrographic Survey Conference.

I especially want to welcome the representatives of the Navy, the Defense Mapping Agency, and the Canadian Hydrographic Service who are with us this week. Although last year's conference was attended by observers from the Navy's Postgraduate School in Monterey, Calif., this is the first time we have formally invited key operations people from other United States or Canadian hydrographic surveying and charting agencies. I extend a special greeting to you people and hope you will take an active part in these proceedings.

Before I go any further I would like to recognize an individual of the National Ocean Survey (NOS) who is about to retire. This, I must say, is no ordinary acknowledgment.

This man has dedicated 48 years of his life to NOS and its predecessor, the Coast and Geodetic Survey, in the field and in the office, both as an officer and as a civilian. His name has long been synonymous with excellence and quality, and he is <u>the</u> recognized expert within NOS on hydrographic surveys both past and present.

Among many other accomplishments, he was a leader in the early art of fathogram interpretation, but most important of all, through his unceasing determination to ensure the safety of navigation, he has kept us honest by making the final inspection of many hundreds of hydrographic surveys, and in so doing has been instrumental in keeping our nautical charts second to none in the world.

This man is truly a living legend, and will always be remembered by those of us in NOS with respect and pride. He will be sorely missed, and we wish him Godspeed in his retirement.

Ray Carstens, will you please stand up?

The U.S. Navy, the Defense Mapping Agency, and the Canadian Hydrographic Service are recognized leaders in fostering international communication between the hydrographic surveying offices throughout the world. Beyond participating and supporting the activities of the International Hydrographic Bureau and its various committees, the Canadian Hydrographic Service annually convenes an excellent forum for the hydrographic and charting communities. Beginning as an in-house effort to develop communication between their

regional centers and headquarters, their annual meeting has developed into a forum considered by many as the best hydrographic surveying conference in the world. The National Ocean Survey has been proud to be able to support these Canadian conferences in the past and will do so again when key staff from the Atlantic Marine Center, Pacific Marine Center, and Headquarters attend the 19th Annual Canadian Hydrographic Conference in Halifax, Nova Scotia, in mid-March.

In looking over this week's agenda, I see that many fine papers will be presented. Papers that not only describe our present operations, but also some that look into the near future to inform us about new initiatives in hydrographic surveying and nautical charting.

I also note that several seminars are planned which should assist us in identifying problems, in frankly discussing, and in seeking solutions to those problems.

I'm sure that all of you will agree that automation, with its attendant sophisticated hardware and software, is here to stay. As the tools we use become more complicated and expensive, we must stay abreast of the work of other agencies and governments in their efforts to accomplish similar tasks. We should increase our cooperative efforts. Let me mention some examples.

This year we have established a committee of DMA and NOS representatives to explore areas in which increased cooperation in research and development could prove fruitful. As a direct result, in cooperation with DMA and NAVOCEANO, we hope to try out one or two global positioning system receivers as early as next October or November.

There is a Memorandum of Understanding between NOAA and NAVOCEANO which provides for cooperation in several areas:

- Diving and biomedicine
- Meteorology
- Hydrographic surveying

As a result of the last item, the Navy has adopted the NOS Hydrographic Manual, with some modifications, and a common format for project instructions has been devised. We are also jointly supporting, with DMA and NAVOCEANO, a graduate studies program in hydrography at the Navy Postgraduate School.

Our efforts in promoting cooperative hydrographic surveying and charting programs can, of course, be identified through the support provided to the International Hydrographic Organization. However, I consider our efforts with the Canadian Hydrographic Service to be highly significant, for we have achieved successes that the international hydrographic community now recognize. From the early days of each agency's existence, we have frequently exchanged basic data in support of each country's nautical charting program. We have coordinated and jointly participated in hydrographic surveys of the waters between each country and are now exchanging personnel and chart compi-

lation material.

Another example of the emphasis we have placed on cooperation is the creation of a United States-Canada Hydrographic Commission for the continued coordination of all future surveying and charting activities scheduled for the contiguous border waters between Canada and the United States. Our aim is to achieve maximum compatibility, uniformity, and interchangeability of all marine charts and related navigational publications produced by both agencies. I am sure you will agree this is a large objective, but, I believe attainable considering our successes to date.

I would like to leave one thought with you as you meet this week, and as we all look ahead into the 1980's. Sophisticated hardware and software are here to stay, yes, but we must be ever aware that these are only tools and will not do our job for us. These tools are not, nor will they ever become, hydrographers or cartographers.

I believe that the role of the human in the system is becoming more important, not less. In our race to utilize the latest in technological advancement we sometimes tend to minimize, or even neglect, the part the human still must play in order that the tools be used properly and efficiently.

We cannot afford to ignore the human needs for timely information, for adequate training, for exercise of the intellect, and for self-expression. Conferences such as this, and the proceedings that are published as a result, can certainly assist us in meeting these human needs. However, we must continue to look for other ways in which to improve the human aspects of our systems. Therein will lie our strength.

When looking into the 1980's, I will be very much concerned with the direction NOS will be taking. I would like to strike a better balance between operations and research and development, in favor of more R&D within NOS.

Nevertheless, I, for one, will still rely on the people of NOS to get the job done. I sincerely appreciate what all of you have done in the past, and I am looking forward to the great strides that we, as people working together, can accomplish in the future.

GLOBAL POSITIONING SYSTEM

Capt. John D. Bossler
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ABSTRACT. The background and future plans for the Global Positioning System will be presented. The geodetic and navigational uses of such a system will also be discussed.

INTRODUCTION

A method that will have tremendous impact on future surveying and navigational technology is the NAVSTAR (Navy Star) Global Positioning System (GPS). The system will eventually employ 24 satellites and should be operational by the late 1980's. GPS will be an efficient way to determine positions to a sufficient accuracy for most geodetic purposes at a relatively low cost.

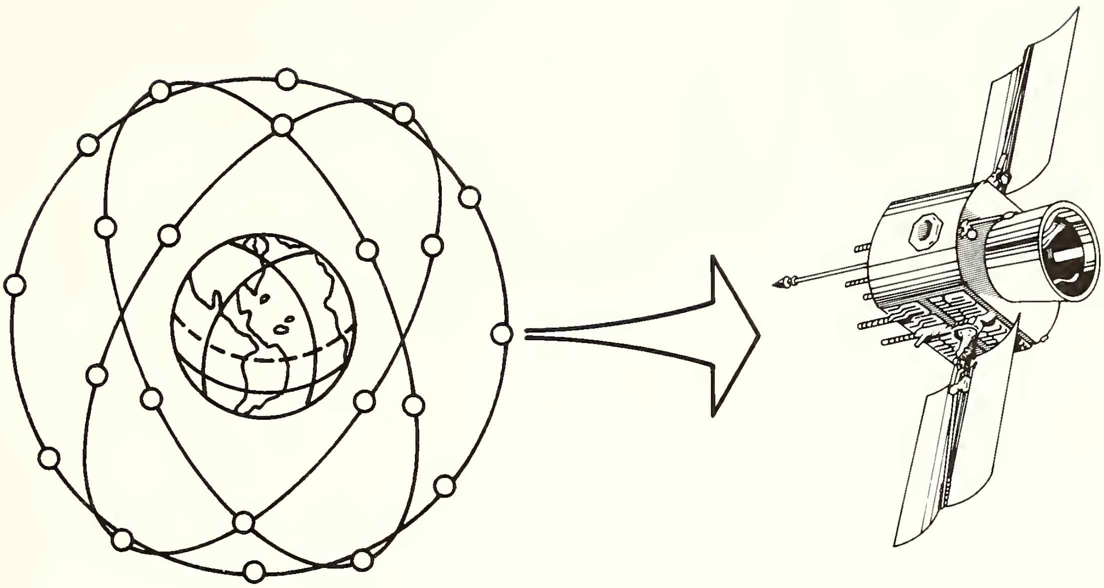
Figure 1 shows eight satellites equally spaced in each of three orbital planes at an inclination of 63°. At least seven satellites will be in view at any location, each in a circular 20,000-km orbit with a 12-hour period. Each 950-lb satellite provides 450 watts (energy) transmitted on two carrier frequencies, 1200 and 1600 MHz. Both quartz and rubidium oscillators form the transmitter system, although some difficulty is now being experienced with the rubidium oscillators. The quartz oscillators are sufficiently accurate for relative positioning using certain techniques. The life expectancy of a GPS satellite is 5 years; however, new satellites will replace old ones as their effectiveness ceases.

DEVELOPMENT PLAN

The development plan for implementing the GPS system is shown in figure 2. Phase 2, also known as D-SARC II, was reached June 1979. Full-scale development and system testing are in progress. At present, four satellites are in circular orbit, with two others being added this year.

The Department of Defense (DoD) has defined segments of the GPS into three areas: (1) the space segment, (2) the user segment which comprises sea, air, and ground equipment and vehicles, and (3) the control system which comprises the master control station and satellite control facilities (fig. 3).

Of primary interest to this audience are the system's navigational features. When the system becomes fully operational, at a cost of several billion dollars, it will probably replace most of today's navigational systems (i.e., Loran, OMEGA, inertial positioning, Navy Transit, Navy navigational



ORBITAL CONFIGURATION

- 12-hr period
- Circular orbits
- 63° inclination
- Eight satellites per plane

SPACECRAFT CONFIGURATION

- 950 lb (typical)
- 450 watts (typical)
- NAV signals: 1200 MHz
1600 MHz
- 10^{-13} clock stability
- 5-year design life

Figure 1.--Segment of Global Positioning System showing orbital and spacecraft configurations.

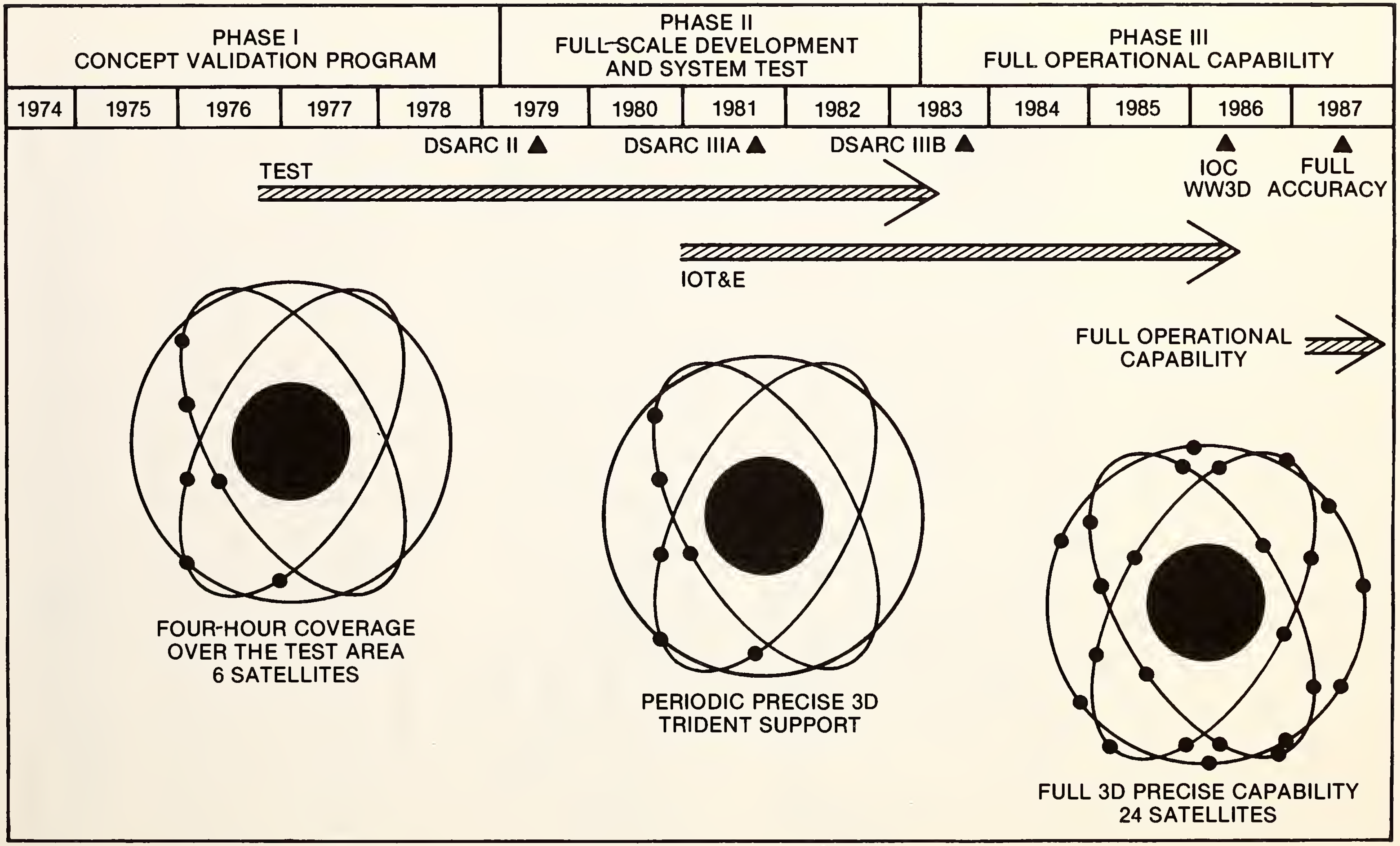


Figure 2.--NAVSTAR Global Positioning System schedule.

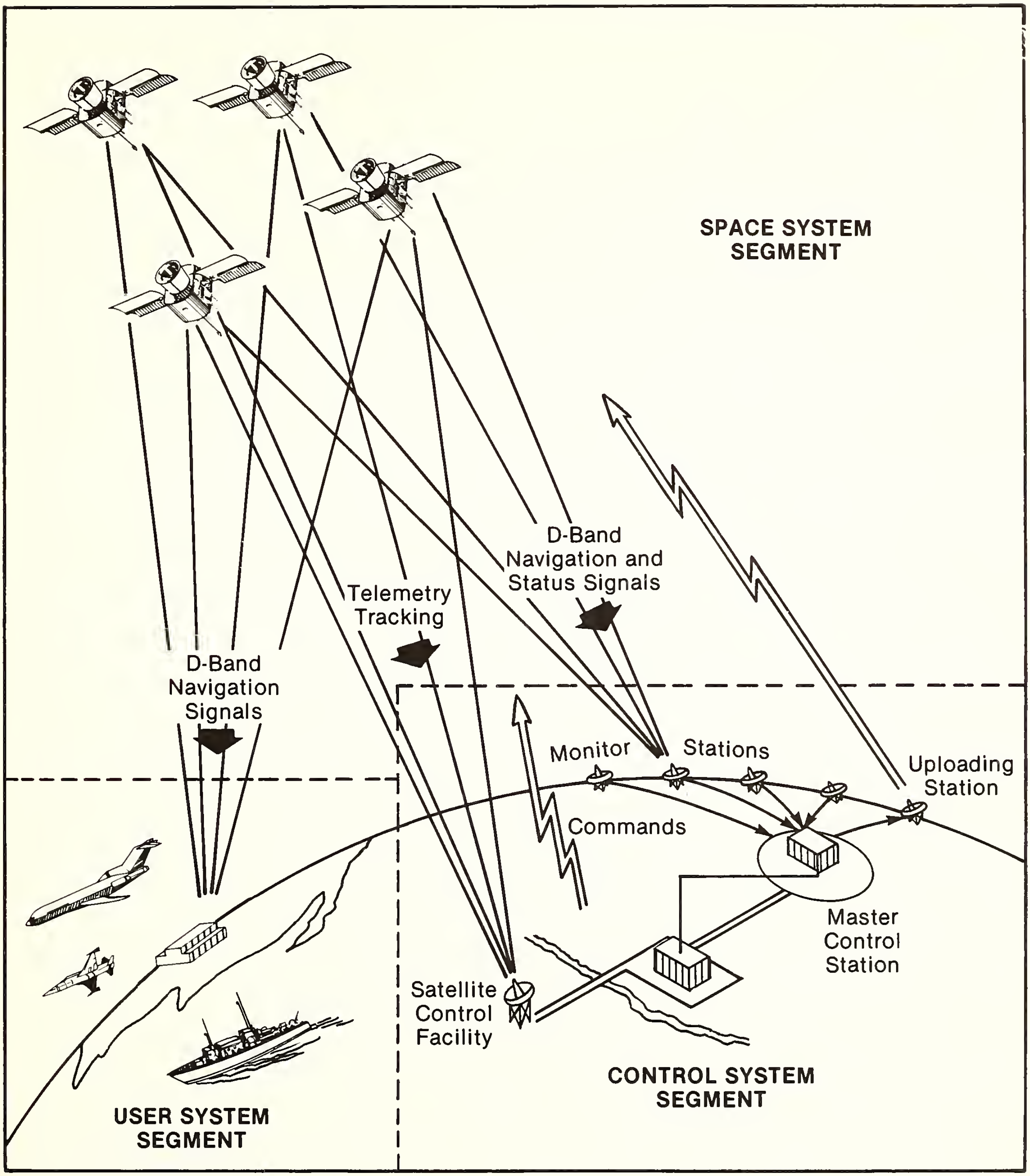


Figure 3.--NAVSTAR Global Positioning System.

satellites, and other systems). The expected accuracy for instantaneous positioning will be about 10 meters at the 90-percent level, with a velocity of about 3 centimeters per second (cm/sec) at the 90-percent level.

PROGRESS

Three Federal agencies are now exploiting GPS for geodetic purposes: DoD's Defense Mapping Agency (DMA), National Aeronautics and Space Administration (NASA), and NOAA's National Ocean Survey (NOS). A current status report (in draft form) is available to this audience, upon request, from NOS's National Geodetic Survey (NGS).

DMA's Naval Surface Weapons Center (NSWC), Dahlgren, Va., is considering the development of a geodetic receiver which will utilize GPS Doppler shifts. NSWC is also investigating, along with NGS's assistance, another technique that uses the phase difference of the reconstructed carrier frequencies, rather than the Doppler shift.

Test results at Dahlgren utilizing the GPS Doppler signals indicate that relative positional accuracies of 10 cm in several days are possible. NSWC wants to improve these figures to obtain, say, 2- to 4-cm accuracies within a period of several hours. We feel these expectations can be achieved.

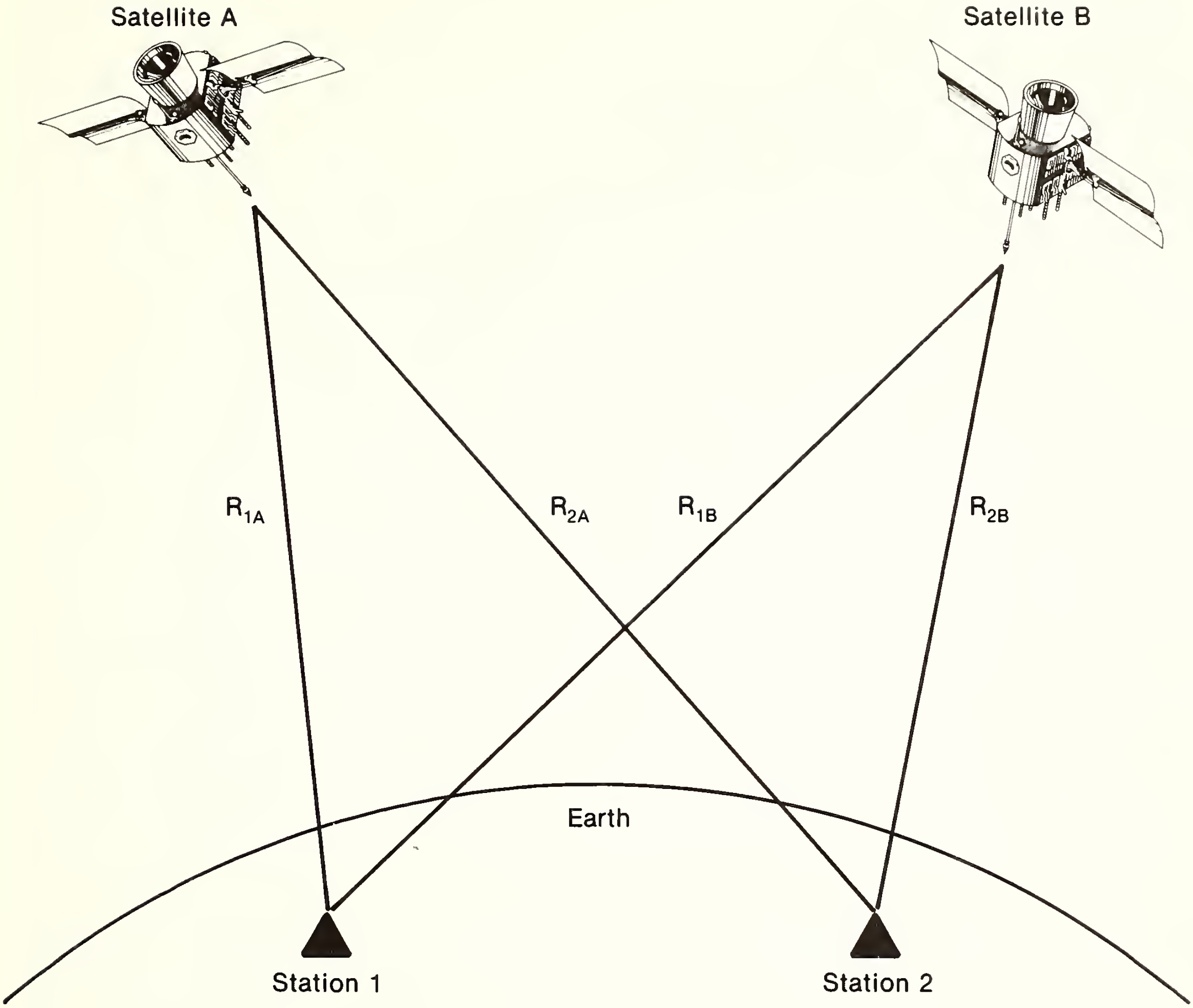
The National Geodetic Survey plans to implement GPS by applying essentially the same developmental method that was used for the Sequential Colocation of Ranges (SECOR) system, a method developed several years ago for geodetic purposes. A range difference will be determined by differencing the ranges from one satellite to one ground station and from another satellite to the same ground station (fig. 4). The station coordinates are clearly a function of the two range differences and the satellites' coordinates. We expect to achieve 2- to 3-cm accuracy, perhaps even 1-cm, in a period of several hours.

Such high expectations imply we have overcome the difficulty of water vapor encountered by GPS satellite ranges as they pass through the tropospheric region of the atmosphere. We plan to transmit signals from a water-vapor radiometer, or similar device, which will sample the water content of the troposphere. Our simulated results, based on four satellites now in orbit over the United States, appear conservative, even pessimistic.

The operational GPS system of the future will give users an enormous geometric advantage. Present accuracies using the Doppler signals from the Navy navigational satellites are at the 30- to 40-cm level, leading us to believe that accuracies of 2- to 4-cm are possible.

NASA is pursuing development of a GPS system called SERIES. Under contract to NASA, the Jet Propulsion Laboratory, Pasadena, Calif., is using the GPS satellites as quasars in a Very Long Baseline Interferometry (VLBI) mode.

In addition to the Doppler technique employed by NSWC, the Department of Defense has another effort in progress at Massachusetts Institute of Techno-



$$f(\vec{X}_A, \vec{X}_B, \vec{X}_1, \vec{X}_2) = (R_{1A} - R_{2A}) - (R_{1B} - R_{2B}) + \text{NOISE}$$

$\vec{X}$ = vector from center of earth

R = ambiguous range from satellite to ground station

Figure 4.--Utilization of the Global Positioning System by NOAA/NGS.

logy's (MIT) Draper Laboratory. Researchers are considering perfecting a new tone--an additional frequency--for the satellite. Together, the research resulting from investigating these two techniques and the phase difference method will result in accuracies to the 1- to 2-cm level. Such an accomplishment would benefit geodesy.

NGS staff members will meet next week with researchers from MIT and NSWC to consider combining the Doppler and MIT methods with the range, or phase differencing method. A cost study is in progress. In addition to the simulations mentioned, NGS has contracted Collins Radio Company to perform a study of market production costs for the radio receivers and other critical factors. By cooperating with DoD and NASA in this venture, NOS will pay only one-third of the developmental costs.

DISCUSSION

Cdr. Chubb: Present development of GPS is aimed at geodetic positioning. Will it also have hydrographic application, by means of a moving platform?

Capt. Bossler: NGS is not pursuing this aspect. Clearly, DoD is incorporating this feature. DMA's representative is Dr. Charles Martin. Possibly the subject may be discussed when the NOS Committee on GPS, which is chaired by Captain McCaffrey, meets in the near future.

Capt. McCaffrey: Will the various signals be coded and will that adversely affect the accuracy?

Capt. Bossler: That's a very good question. The carrier frequencies are coded for defense applications. In the SERIES mode, this coding will not affect the system. The transmission is the same as for random (quasar) signals. As a bona fide user of GPS, authorized NOS personnel will have access to the key to the code.

Mr. Beaton: Regarding the application of GPS to hydrography, some work was done last year with a moving platform. An LCU (landing craft) was used off the west coast with different antenna heights. The committee chaired by Dr. Martin is composed of representatives from DMA, Navy, and NOS. It met several weeks ago to develop an experimental plan. The plan should be ready in 10 to 12 months. The financial force behind the GPS plan, for the present at least, has not been in the field of geodesy. Therefore, GPS will not provide us with all the navigational features we desire. Final implementation is expected between 1988 and 1989. The total number of satellites may be reduced to 18 instead of 24, presumably with no loss in accuracy. For the commercial user, the accuracy of the GPS system will probably not be as high as mentioned here today. It may be a sore point in the future, but the mapping community should be aware of it.

Capt. Bossler: Thank you very much for your comments. You know far more about the navigational aspects than I do. Many groups are now working on GPS, so it isn't surprising that this information has yet to be disseminated.

APPLICATION OF HYPERBOLIC LORAN-C TO HYDROGRAPHIC SURVEYING*

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ABSTRACT. The possible application of hyperbolic Loran-C as a positioning system for hydrographic surveys was investigated. Differential Loran-C techniques and geodetic calibration procedures were examined as methods of substantially improving position accuracy. A field test was conducted in Monterey Bay, Calif., comparing positions from the 9940-Y and W rates of the west coast Loran-C chain with those derived from a microwave positioning system. Overland propagation corrections for the test area are presented. Test results suggest that scrupulous application of the differential technique and rigorous calibration procedures can improve the absolute position accuracy of a mobile Loran-C receiver--to something less than 100 meters (drms) in this test. This discussion and cited references indicate that receiver error and unresolved ground wave propagation effects are the largest sources of error in the positioning system. A bibliography of recent literature is included.

INTRODUCTION

Hypothesizing that hyperbolic Loran-C positioning might be suitable for some small-scale survey applications, a field comparison between a commercial Loran-C receiver and a microwave positioning system was conducted in Monterey Bay, Calif., during the summer of 1979. Accuracies in the range of 40 to 60 meters (drms) relative to the survey datum were indicated by this comparison (Schnebele 1979). Unfortunately this falls short of the accuracy requirements for even the smallest scale routinely used--1:80,000. These results are, however, just one example of a particular system's capability. All evidence on other possible system configurations and procedures is not yet in. Consequently, it is not the intent of this discussion to pass final judgment, but rather, to review some of the considerations implicit in operating an "improved accuracy" Loran-C system. This brief presentation and the included bibliography should be a useful starting point for other nonexperts venturing into the Loran-C subject.

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*Based upon a project conducted while assigned to the Naval Postgraduate School, Monterey, Calif., in the Oceanography (Hydrography) Curriculum, 1977-1979.

The Loran-C system performance is presently limited by receiver capabilities and unresolved ground-wave propagation effects. The differential technique has been shown to significantly improve the temporal stability--repeatability--of a Loran-C system (Goddard 1973). Other cited references and the Monterey Bay comparison data imply that receiver errors and difficulties associated with calibration of the Loran-C grid result in the largest uncertainties as shown in table 1 of the summary section. Each of these considerations is discussed in turn with a summary of estimated errors presented in the conclusion.

GEOMETRIC DILUTION OF PRECISION

Hyperbolic Loran measures time differences, usually in units of microseconds. The uninitiated readily lose perspective without the method to convert errors expressed in time units to distance errors. Because of the hyperbolic geometry involved, this conversion is not constant; but it can be approximated by a variable gradient in meters/microsecond (m/ms) which is termed the Geometric Dilution of Precision (GDOP). Its functional form is derived in any of several references (Atlantic Research Corp. 1962, p. 130). The GDOP factor expresses the combined effect of lane expansion and varying intersection angles between the hyperbolic arcs. For the purpose of this discussion, it suffices to note that over the coastal waters of the United States, the GDOP varies from about 200 to 2,000 m/ms. Given a 0.1-ms change in each of the two rates needed for a fix, then the position is shifted from 20 to 200 m depending on the local GDOP factor.

TIME DIFFERENCE EQUATIONS

Each Loran rate is a measurement of the difference between arrival times of the signal pulses from the master and respective secondary transmitters. Referring to figure 1, the rates TDW and TDY measured by a receiver located at R would be composed of:

$$\begin{aligned} TDW &= ED_w + t_w - t_m \\ TDY &= ED_y + t_y - t_m \end{aligned} \qquad (1)$$

where the ED terms represent the preset emission delays of each secondary relative to the master, and the t terms represent the travel times from the respective transmitters to the receiver.

In order to compute a position for the receiver using the equation pair (1), the position of each transmitter and the emission delays must be given. In addition, some relation between travel time, t, and geodetic distance, D, must be assumed. Representing this general relation as:

$$t = f\ (D,\ldots),$$

which indicates that the travel time, t, is some function, f, of the geodetic distance, D, traveled and some unspecified list of other independent variables. With this form, equations (1) become:

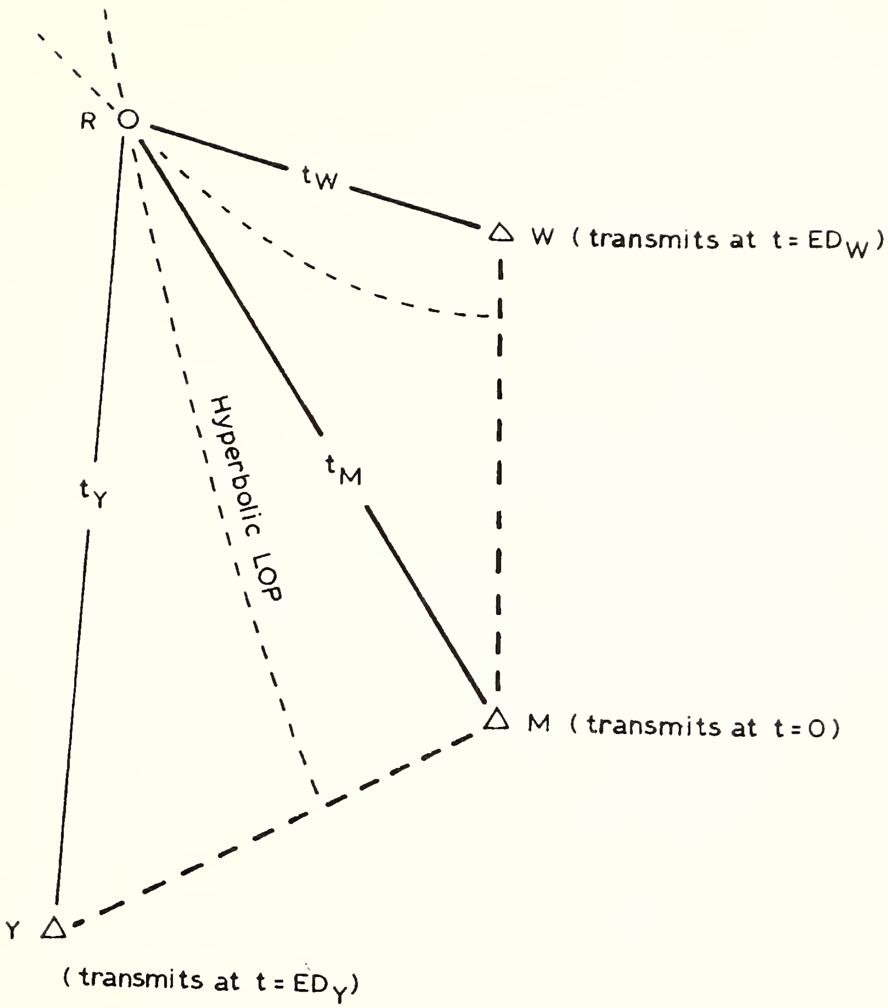

Figure 1.--Components of time difference measurement.

$$TDW = ED_w + f\,(D_w,\ldots) - f\,(D_m,\ldots)$$
$$TDY = ED_y + f\,(D_y,\ldots) - f\,(D_m,\ldots). \qquad (2)$$

The solution for the receiver position is an iterative procedure in which an estimated position is chosen, the geodetic distances computed, and rates predicted using (2).

The predicted and observed rates are compared, and a new estimated position chosen. The procedure is repeated until the observed and predicted rates agree to within some allowable tolerance (for example, Campbell 1965). Writing the time difference equations, as in (2) above, makes explicit the importance of properly selecting the time-distance relationship expressed by f(D,...).

GROUND WAVE PROPAGATION AND CALIBRATION

Propagating as a ground wave, the time-distance relation for the Loran-C signal is a complicated function of the geophysical properties along the signal path as well as the geodetic distance. Spatial and/or temporal variations in surface conductivity and permitivity, hypsography, atmospheric lapse rate, and index of refraction induce significant changes in the actual travel time of the Loran-C signals. Several methods have been proposed for incorporating such detail into Loran-C position computations, or equivalently, grid predictions. The work of Johler (1969) and Doherty (1972) typify Loran-C prediction methods in which spatial variations of these properties are included. These prediction methods require data on the geophysical properties along the signal path and/or empirical calibration data from which these properties can be estimated. The present Loran-C grid prediction procedure used by the Defense Mapping Agency incorporates some of these considerations. The Loran-C calibration projects being conducted by the U.S. Coast Guard and NOS are designed to provide data for improving this grid prediction procedure. Eventually this work will lead to improved accuracy in operational Loran-C positioning systems, but present systems are limited to a much simpler time-distance model which is discussed below.

Most Loran-C computation techniques assume that the signal propagates over a seawater path and through a standard atmosphere. If the effects of overland propagation are considered at all, they are represented by a small, additive correction to the time-distance relation. In this type of propagation model, the time-distance relation is expressed as,

$$t = \frac{n}{c}D + \Psi + \varepsilon \qquad (3)$$

where the term $\frac{n}{c}D$ is called the Primary Travel Time with c representing the free space velocity; n, the index of refraction at the surface of the standard atmosphere; and D, the geodetic distance. The Secondary Phase Factor, Ψ, is the computed delay of a signal traveling over a seawater path of length D (Johler et al. 1956). The additional Secondary Factor, ε, represents the additional delay caused by overland propagation. Substituting this form into the time difference equations (2) gives:

$$TDW + (\varepsilon_m - \varepsilon_W) = ED_W + \frac{n}{c}(D_W - D_m) + \Psi_W - \Psi_m \qquad (4)$$

with a similar expression for TDY. Everything on the right-hand side of equation (4) is a known or computable quantity. It only remains to determine the ($\varepsilon_m - \varepsilon_W$) term which has been called the overland propagation correction.

Present practice has been to either ignore this term or estimate it from field calibration data. In order to appreciate the complexity of the calibration task, consider figure 2 which shows the theoretical form of the additional Secondary Factor for three hypothetical paths with differing proportions of land and sea (Wait and Walters 1963). Referring to figure 3 which shows the west coast Loran-C stations, the indicated path distances are roughly 400, 600, and 1,100 km to the master, Y and W transmitters, respectively. Scaling approximate values for ε from figure 2 with these path distances suggests that the overland propagation corrections, ($\varepsilon_m - \varepsilon_W$) and ($\varepsilon_m - \varepsilon_y$), should be on the order of -1.1 ms and -0.3 ms, respectively. Although this model correctly predicts orders of magnitude, the actual corrections derived from the Monterey Bay Field Comparison, figures 4 and 5, show a complex spatial pattern which is not readily explained by curves as simple as those in figure 2. Clearly, the overland corrections cannot be ignored without risking errors on the order of a microsecond. A subjective interpretation of the Monterey Bay data suggests that accuracies of 0.05 ms might be achieved with sufficient calibrations. In other localities, however, the spatial variation in the corrections is so large it may be impracticable to calibrate with sufficient density. The mountainous coastline of British Columbia represents such a worst-case area (Eaton and Mortimer 1979).

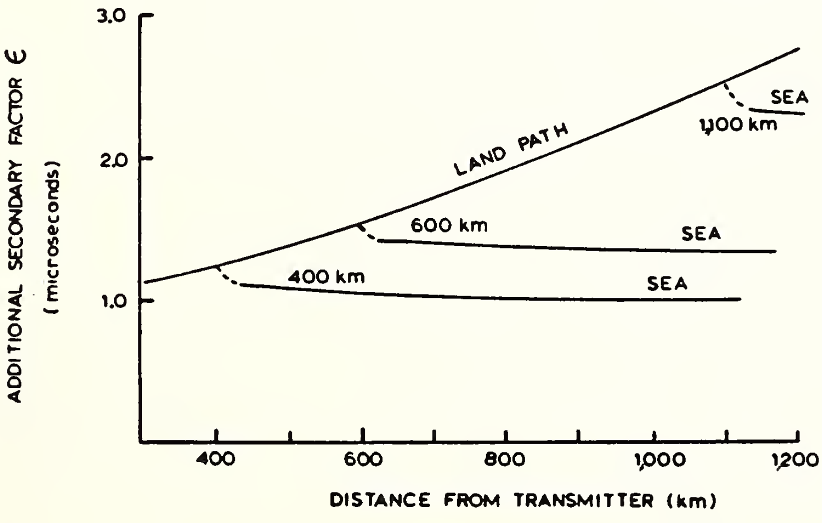

Figure 2.--Variation of additional secondary factor with distance on typical land-sea paths. (The curves assume a uniform land conductivity of 0.01 mho/m and a relative permitivity of 15. The sea path values are 4 mho/m and 80, respectively. The phase recovery effect at the coastline is symbolized by the dashed portions of the curves.)

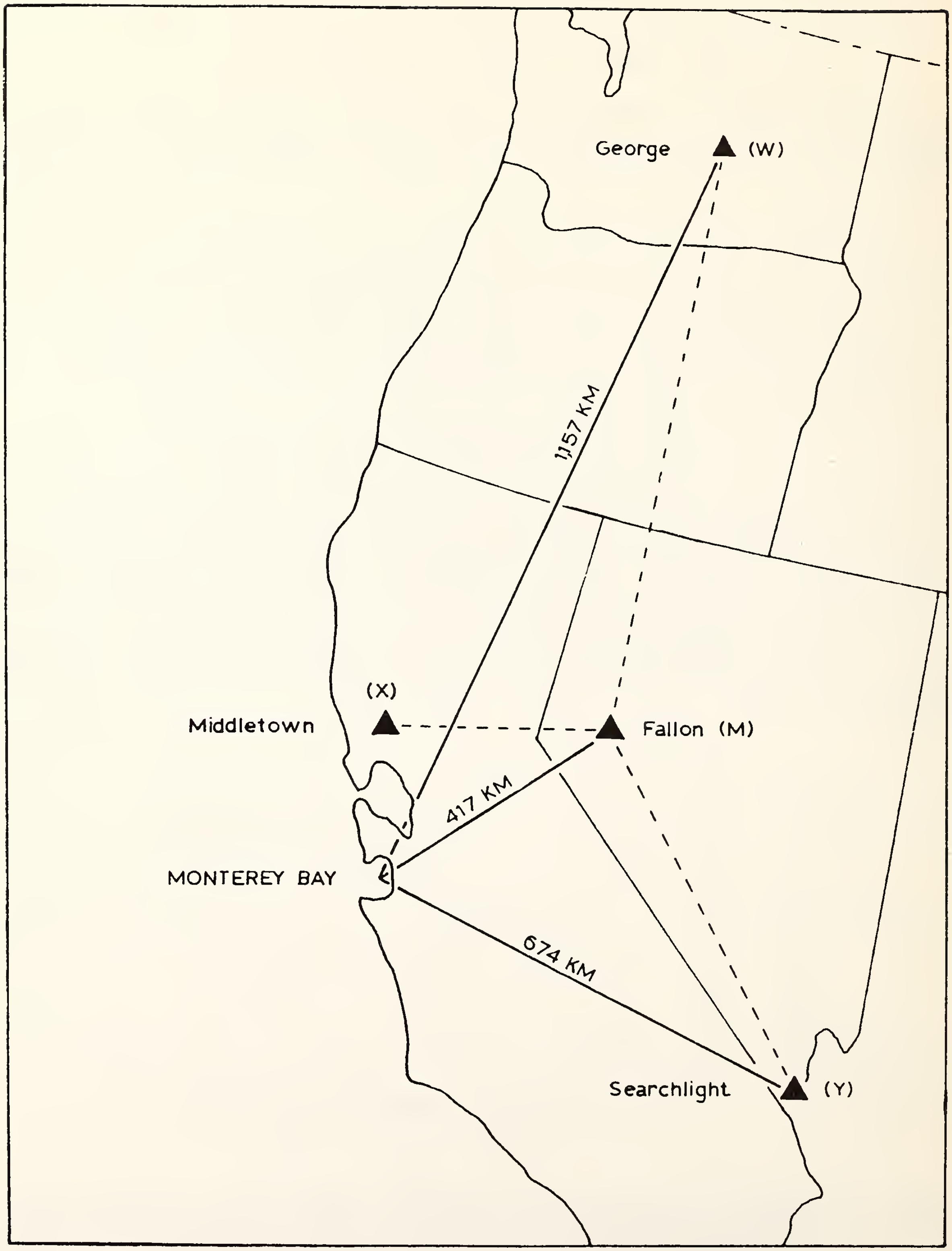

Figure 3.--Location of west coast Loran-C stations.

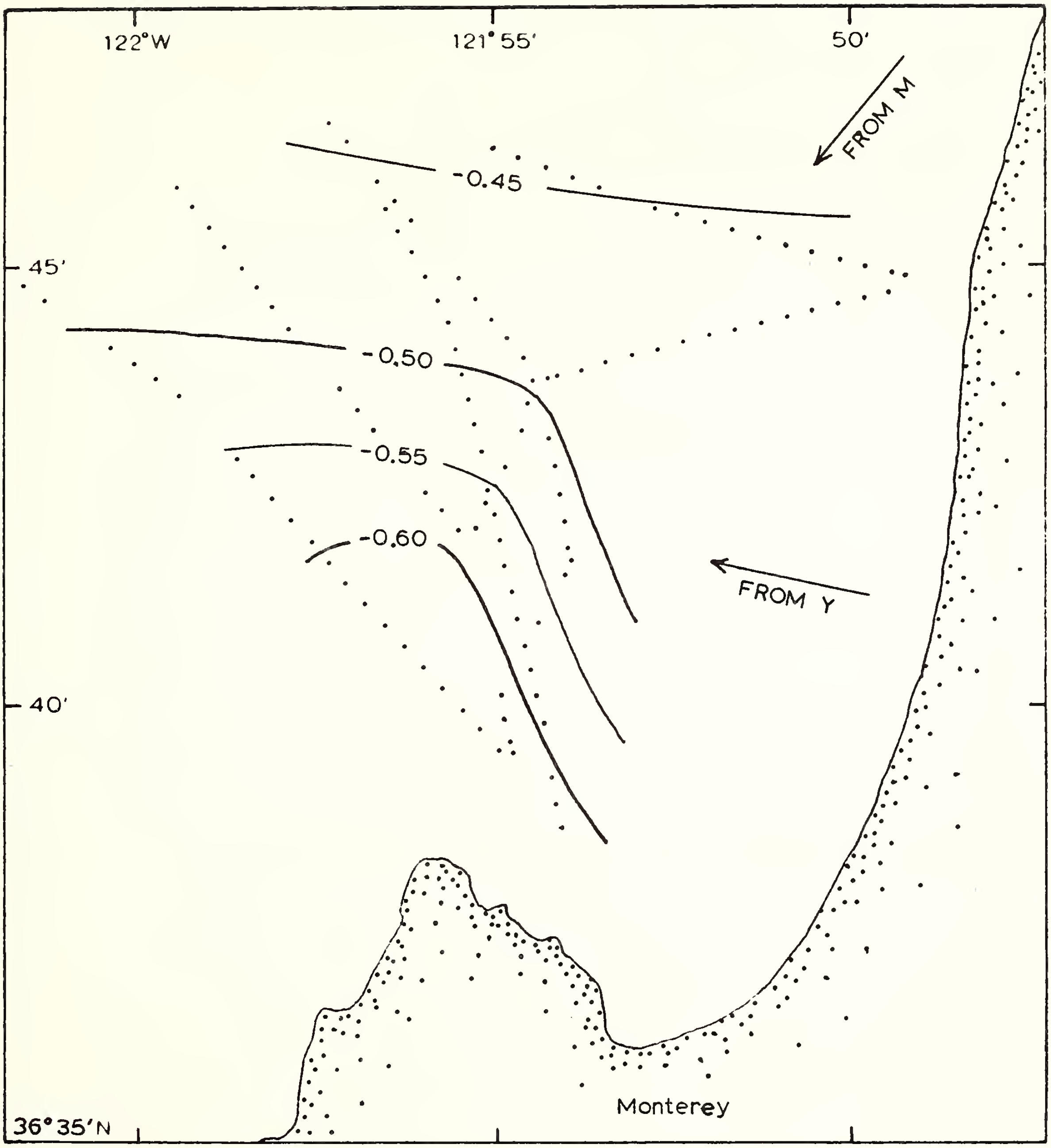

Figure 4.--Overland propagation corrections for 9940-Y rate.

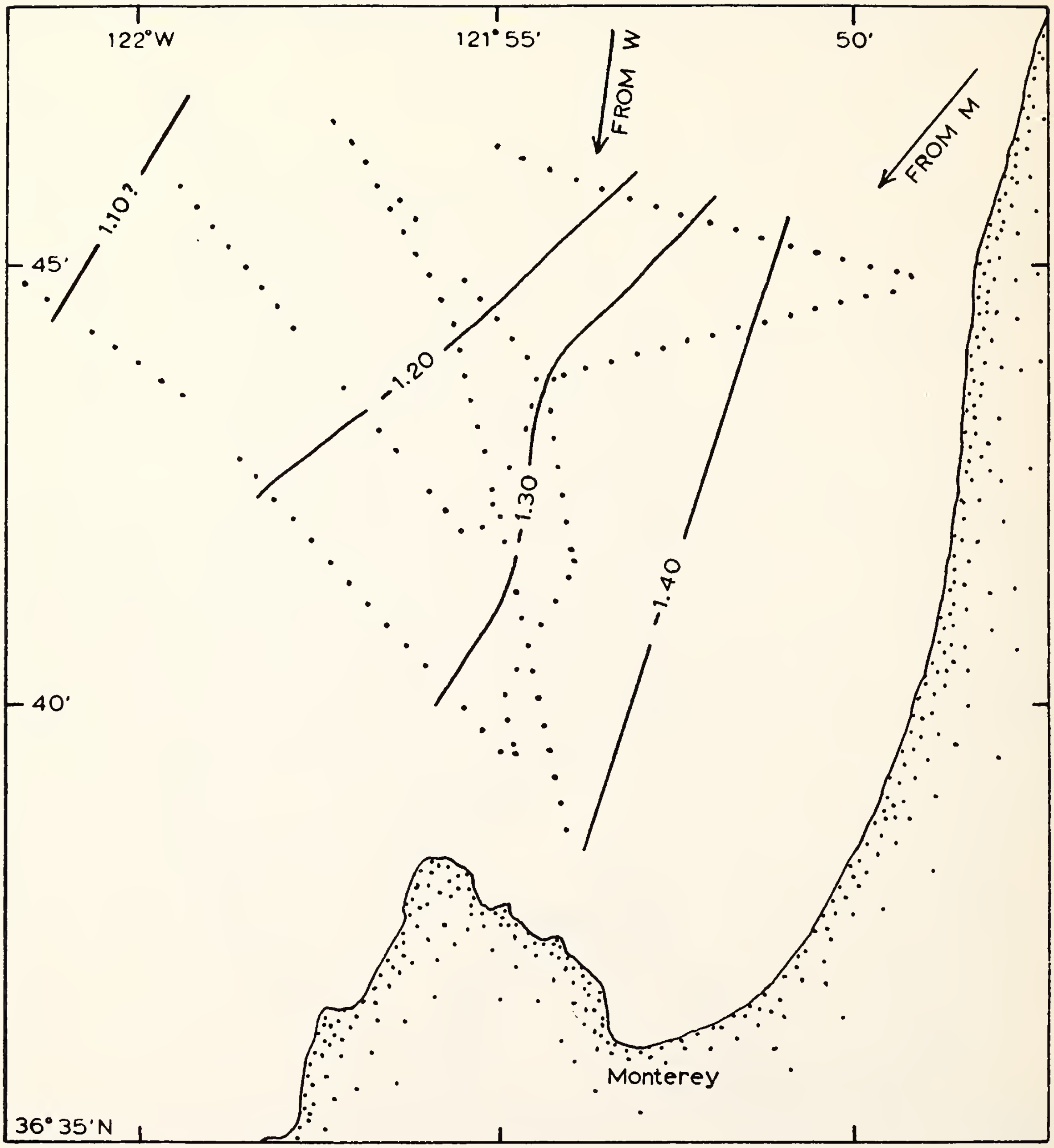

Figure 5.--Overland propagation corrections for 9940-W rate.

TIME STABILITY AND DIFFERENTIAL LORAN

Temporal changes in the propagation conditions and instabilities in the transmitting equipment are potential sources of error. It has been shown, however, that the differential correction technique can effectively eliminate these errors in at least localized areas. One study (Goddard 1973) achieved temporal stabilities of better than 0.02 ms (one standard deviation) for stationary receivers located around Delaware Bay.

In the differential technique, fluctuations in the observed rates at a fixed monitoring receiver are used as corrections for other receivers in the nearby area. The Delaware Bay study obtained its improved stability for separation distances of up to 130 km between the monitor and remote receivers. This correlation of temporal fluctuations over considerable distances is essential if a shore-based monitor is to provide useful corrections to a survey vessel operating offshore. Veronda (1977, p. 33) has suggested that the correlation distance may be as great as 240 km if the monitor is located along the signal path to the working area.

It is interesting to note that the System Area Monitor (SAM) stations associated with each Loran chain apply differential-type corrections to the Loran rates in real time. These SAM stations continuously monitor the signals from all transmitters in the chain. If the observed time difference deviates by more than 0.05 ms from its expected value, then the appropriate secondary is instructed to adjust its emission delay time in order to remove the error (WGA 1976a). These real-time corrections are intended to control timing errors between stations, but they also pick up any changes in the propagation conditions which may occur on paths from the transmitter to the SAM site. In comments on the remarkable stability of the Loran rates in San Francisco Harbor, Illgen and Feldman (1978) noted that the operation of the SAM at Point Pinos, which is some 180 km to the south, produced a situation closely resembling differential Loran-C.

Temporal fluctuations with amplitudes of 0.1 ms and 0.6 ms, and periods of 1 hour and 3 days, respectively, have been documented as weather-related (Doherty and Johler 1976). Annual variations of 0.7 ms due to seasonal changes in the atmosphere and underlying surface have been observed (Veronda 1977, p 31).

Although the SAM stations correct for some of these fluctuations, proper application of the differential technique should ensure time stability on the order of 0.02 ms within most coastal survey areas.

During the Monterey Bay Field comparison, the SAM station at Point Pinos, on the southern shore of the Bay, was used as the differential monitor. Its records showed only one brief fluctuation of 0.04 ms; while during the rest of the comparison period, the fluctuations were less than 0.01 ms.

RECEIVER ERRORS

Receiver errors are a function of the signal strength, signal-to-noise ratio, amount of skywave and cross-chain interference, velocity and/or acceleration of the receiver, and receiver design. Interference problems are minimal, because of phase coding applied to the transmitted pulses and time relationships between adjacent chains (WGA 1976b). The speed of typical hydrographic survey vessels is less than 20 knots, and its effect can be eliminated by appropriate sampling and filtering techniques.

Under favorable signal-to-noise conditions, several commercial receivers have exhibited time difference errors with a standard deviation of less than 0.1 ms (WGA 1977). This is obtained with averaging times on the order of a few seconds, corresponding to an average of 10 to 100 measurements depending on the repetition rate of the chain. A performance goal of 0.05 ms is not unreasonable. Improved receivers can be expected in the next few years. Longer effective averaging times can be achieved by designing processing schemes which incorporate ship course and speed data. Improved performance in stationary receivers has already been demonstrated; for example, Goddard (1973) used 100-second averages and achieved standard errors on the order of 0.01 ms.

Signal-to-noise conditions also affect performance. Favorable conditions are 10 dB or better. In designing the Loran chains, power outputs are chosen to provide suitable signal strengths in the coverage area. At about -4.8 dB, most receivers begin to exhibit increasing errors until some minimum value is reached and the receiver ceases to track the signals. For more information on receiver performance under varying conditions, Veronda (1977) has a comprehensive list of available literature. The implication for hydrographic work is that signal strength and signal-to-noise information must be collected in order to insure data quality. Several commercial receivers already provide these outputs.

SUMMARY

Table 1 summarizes the preceding discussions on sources of time difference errors and the effectiveness of the various techniques to correct for them. The reader is cautioned that these are estimated errors derived from many different sources. There have been few field tests in offshore areas with sufficient accuracy to validate some of these errors.

Table 1.--Estimated Loran-C time difference errors. (Not statistical results, but estimates of one standard deviation in microseconds.)

Sources of Error	Potential Error	Residual Error after Correction by System Area Monitor	Residual Error (4) after Correction by Differential Monitor within Correlation Distance	Residual Error after Calibration by Measurements	Net Error Estimate after all Corrections
Mobile Receiver	0.1 (2)	- -	- -	- -	0.10
Temporal Instability					
Transmitter Timing	- -	0.05	0.02	- -	0.02
Weather-related	0.6	0.2 (3)	0.02	- -	0.02
Annual	0.7	0.05	- -	- -	0.05
Overland Propagation					
Typical Offshore Areas	0.4 - 2	- -	- -	0.05	0.05
Worst-case Areas	2 - 3	- -	- -	(5)	?

(1) Data summarized from text and similar table in Veronda [1977, p.31].

(2) Mobile receiver error may be reducible to 0.05 with proper velocity compensation.

(3) Unusual weather patterns may increase this to 0.60 if operating away from SAM.

(4) Data suggested by Goddard [1973].

(5) Probably impracticable to calibrate with sufficient density.

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DISCUSSION

Cdr. Rossi: Just to point out for those who are unaware, you can't perform a close comparison with what you have on the nautical chart. The nautical chart Loran lines do take into account the secondary corrections; however, to fit it on the Mercator projection, you have to take an average value and apply it to the chart. As you get to the edge of a nautical chart and compare lines to the next nautical chart, even at the same scale, the Loran lines in actual latitude and longitude do not agree. And a further problem, the Loran tables and Loran station position are not on the Clark's ellipsoid.

Lt. Cdr. Schnebele: Yes. The commercial Loran receivers you buy will usually do their computations on the World Geodetic System, WGS '72, datum. Some of the newer receivers may have a capability to select the datum used. You can have it on WGS '72 so it will match with your satellite, or you might select NAD 1927 so it will hopefully match with the NOS chart. But these questions of which datum and which projection to use are answerable for each localized survey area, the question of what to do with the unresolved propagation correction is not.

Cdr. Richards: Have there been any studies performed further offshore to show the stability of the correctors; say, 50 to 100 miles offshore?

Cdr. Schnebele: No. And I think that's a question needing further study. None of the models for predicting the correctors have really been tested offshore. Most of the tests have been run right at the coastline or for inland areas, where there's a question of using Loran-C for aircraft or what they're calling automatic vehicle tracking; e.g., a police department can track where their vehicles are in a city.

But there haven't been any real offshore tests. If these NOS projects continue, where we have ships running medium frequency systems against Loran, we might get some better information on the stability and predictability of offshore correctors.

Incidentally, the bibliography in this paper may be of help in guiding others to find out what tests have or have not been run.

Mr. Grant: We've been using the Rho-Rho Loran-C off Labrador for about the last 6 years, and when we first started to work there, we went with what we thought were the corrections to the Cape Race transmitter. As you move toward the coast, the amount of land path increases until you're next to the coast. If you ignore the coast completely, you can have errors amounting to 3-1/2 to 4 microseconds. We had to face that problem fairly early, therefore, we went with predictions which had to be adjusted slightly, once we were there, by comparing the Loran ranges with ranges we computed from the satellite fix positions. We found by adjusting the predictions, that the overall shape of the overland phase-length correction as a function of the azimuth from Cape Race remained about the same. We ended by just shifting the line up or down to account for the slightly different conductivity that we used in our initial estimates.

Since then we've done two tests there. The first year, 1972, we collected, I guess, about 200 or 300 satellite fixes and computed the range to Cape Race. We compared those satellite fixes with the observed range and computed an estimate for the conductivity. We did a similar experiment in '75. We set up a Decca transmitter on one of the islands, and used that transmitter, together with the range from Angissog, on the southern tip of Greenland, which was all over water, to position the ship. From those positions, we measured the range to Cape Race. Again, we found that the shape of the curve was almost identical, except that the curve shifted slightly between the 2 years. We think it might be because the first year was very wet and during the next experiment, 2 years later, it was quite dry. The amount of shift could be due to the slight change in conductivity. We've been using those corrections there ever since. We seem to be getting fairly good agreement.

Lt. Cdr. Schnebele: How far offshore were you?

Mr. Grant: From a couple of hundred miles offshore, right into the coastline.

Lt. Cdr. Schnebele: At the time I started looking into this, it was obvious that you're better off with a range-range Loran-C. You avoid all the problems of hyperbolic geometry where you lose accuracy just because of the lane expansion.

My goal was to find a very cost-effective (i.e., cheap) method, and that would be hyperbolic. The atomic clocks associated with a range-range system can be rather expensive. But range-range Loran-C is definitely one of the possible methods of obtaining substantially improved accuracy out of Loran-C. The propagation corrections are still required, but they may be easier to handle.

Any other questions? Well, thank you.

CALIBRATING U.S. COAST GUARD LORAN-C
ON THE EAST COAST AND THE GREAT LAKES

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ABSTRACT. The U.S. Coast Guard is conducting a study to determine the accuracy of Loran-C and then calibrating the system when discrepancies are found. They have conducted this program on the east coast, west coast, Gulf Coast, and the Great Lakes for several years and plan to continue it until sufficient data have been obtained to issue accurate values for all Loran-C chains. The NOAA Ships WHITING and PEIRCE each completed one of these surveys for the U.S. Coast Guard. The WHITING's survey covered a series of tracklines from Long Island, N.Y., to Norfolk, Va., using range-range Raydist for positioning control. The PEIRCE's survey covered Lake Huron, using Argo range-range and Del-Norte range-range control.

This paper covers the methods used to obtain the required horizontal control position accuracy. Several new ideas involving project design, shore station movement, and logistics were implemented on these projects to improve efficiency. The ship's position was determined using standard hydrographic survey techniques, with the exception that numerous electronic control station moves were required while the ship was underway. This is due to the fact that a large geographic area is covered in a short time span, and one range-range chain may be used for only 1 to 4 days before switching to a new chain. Also, this paper discusses problems encountered on fresh water, such as using Argo on Lake Huron or similar types of medium range positioning systems, and the determination of the propagation velocity of this type system over fresh water.

At the request of the U.S. Coast Guard, the NOAA Ships WHITING and PEIRCE have each conducted surveys to determine discrepancies between predicted Loran-C values (charted) and the actual observed values. The WHITING's project covered a series of tracklines from Long Island, N.Y., to Norfolk, Va., in 1978 (see figs. 1 and 2), and the PEIRCE's project was a series of tracklines that covered Lake Huron in 1979 (see fig. 3.)

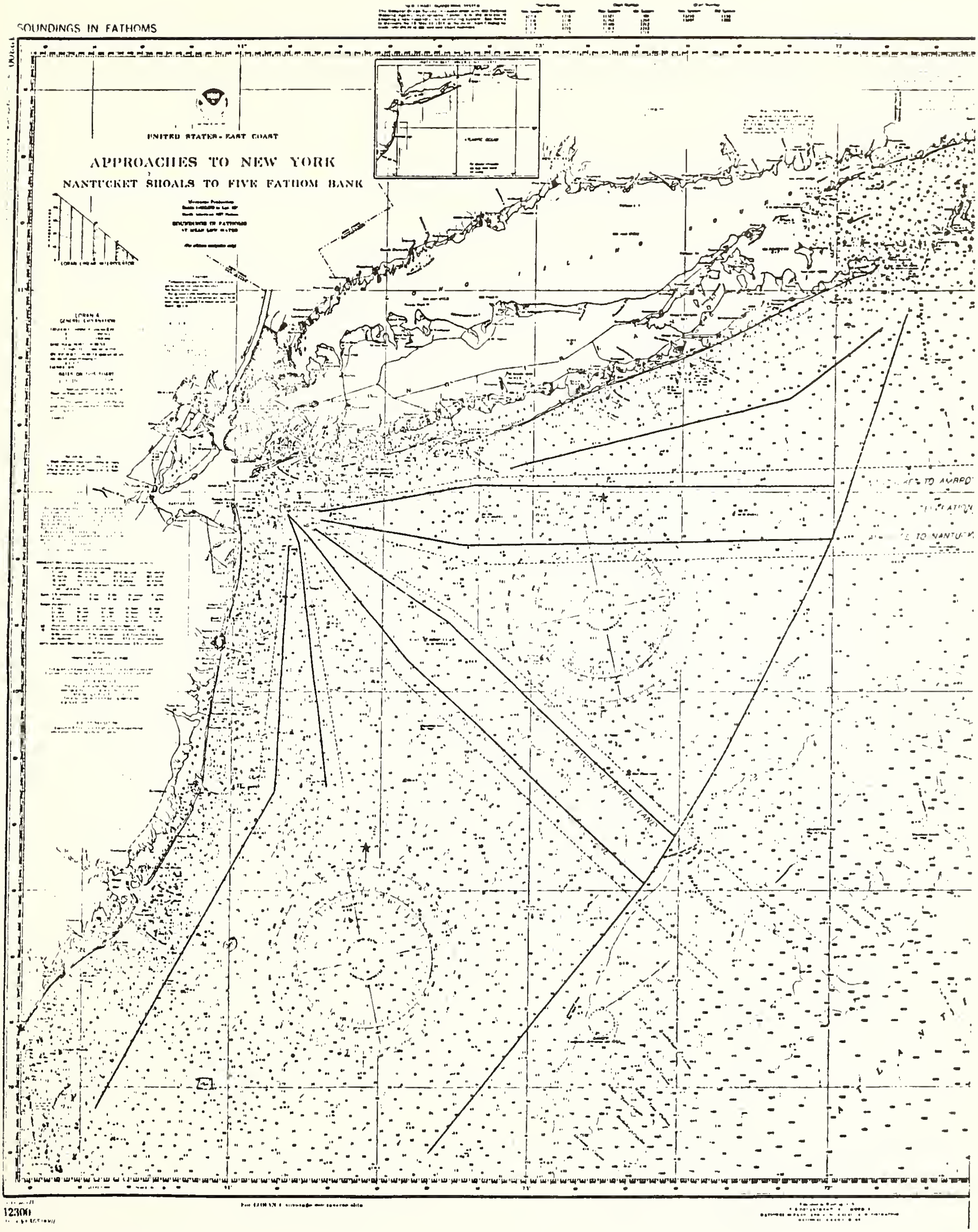

Figure 1.--Tracklines from Long Island to Delaware Bay.

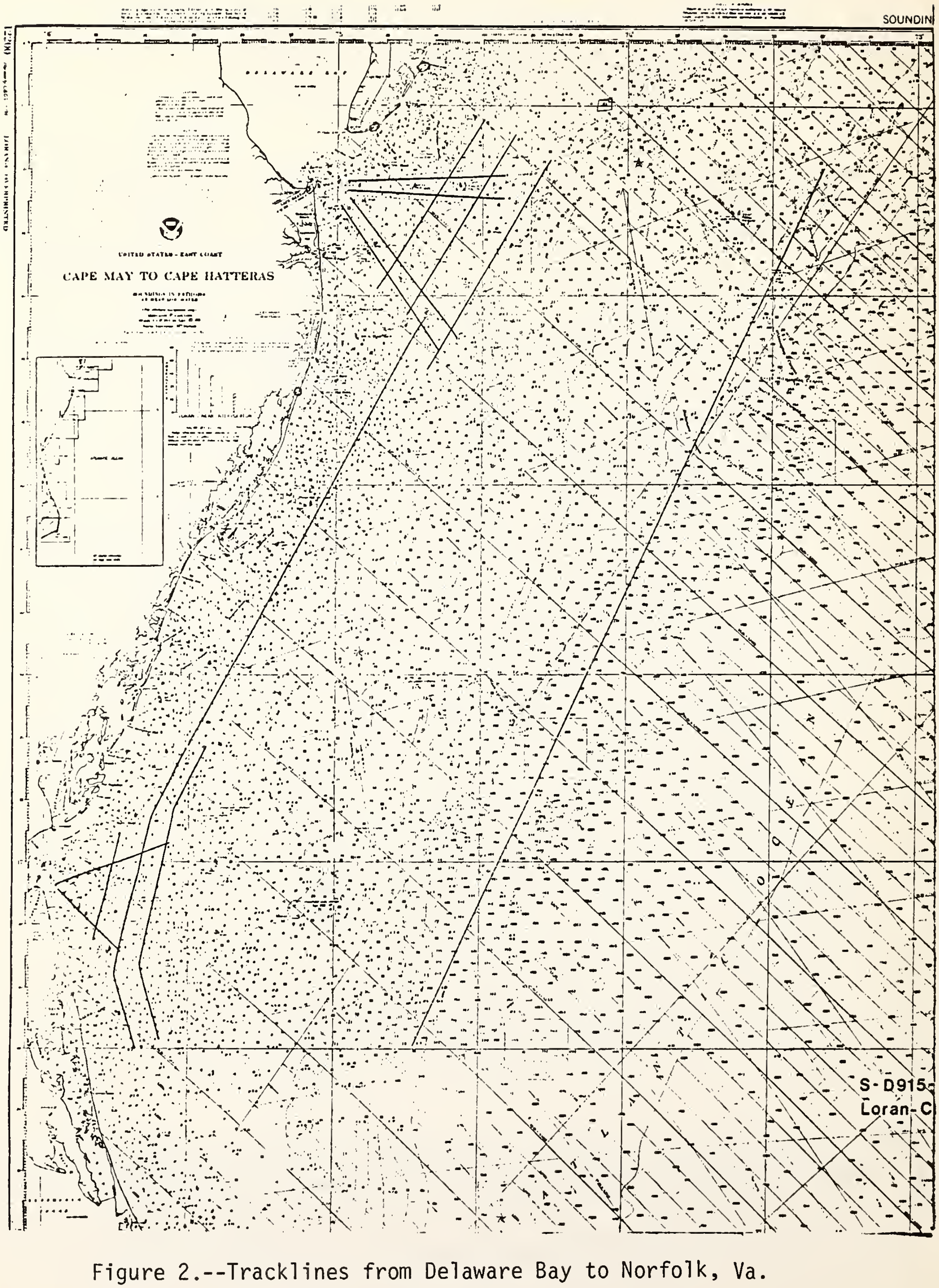

Figure 2.--Tracklines from Delaware Bay to Norfolk, Va.

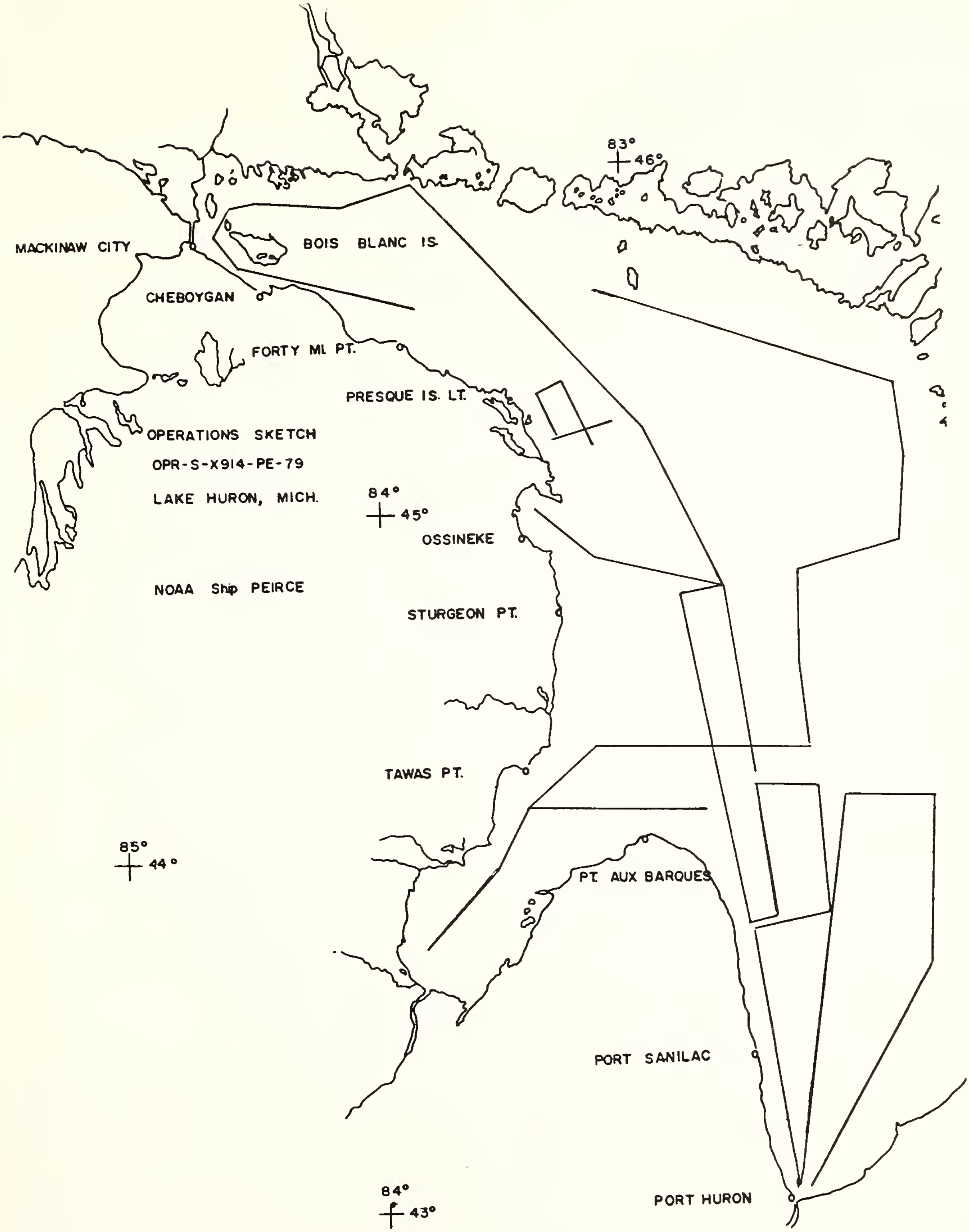

Figure 3.--Lake Huron tracklines.

The projects entailed obtaining an accurate (maximum error of ± 50 meters) position every 3 minutes along predetermined tracklines selected by the U.S. Coast Guard. These tracklines were usually along areas of heavy commercial traffic routes and entrances to major ports and harbors. The position of the WHITING on its project was determined by range-range Raydist and the PEIRCE's position determined by range-range Argo and/or range-range Del-Norte.

The time and position obtained by these systems were logged by the ship's hydroplot systems while simultaneous (maximum of 1-second difference) Loran-C rates were received and recorded on a Texas Instrument TI 733 cassette terminal. The Loran-C receiving units and TI 733 terminal were provided, installed, and manned by U.S. Coast Guard personnel.

The end result of each project was to obtain a print-out of time, position, and observed Loran-C rates at 3-minute intervals along the tracklines. The observed Loran-C rates would then be compared to the published (charted) values and corrections applied. This would seem to be a relatively simple task with procedures similar to routine hydrography with the exception that obtaining soundings is not required. The major difference is that the vessel collecting the data is moving from one area to another at a very rapid pace. This requires that numerous predetermined sites for Raydist, Argo, or Del-Norte shore stations and calibration areas be available for immediate use.

In order for the ship to operate with a minimum amount of time waiting for horizontal control, four shore stations should be available, with at least three in operation simultaneously. This will allow a minimum of two range-range chains to be available for use at all times. When the ship completes the tracklines covered by one chain, it can then calibrate the new chain and continue the project with little time wasted.

While the ship continues its tracking, the shore-based personnel will be moving the shore station no longer required to the next predetermined site for use in the next range-range chain. This "leap-frogging" procedure is used for the entire project.

As stated before, Raydist control was used for one project, and Argo control supplemented by Del-Norte equipment were used for the other project. Four complete shore stations were available with both medium range systems. Due to some unique capabilities, the Argo system seems to be the best system for this type project. These capabilities are as follows: (Please bear in mind that this is not meant to degrade Raydist as it is an excellent system that has proven itself through the years.)

1. The Argo shipboard receiver can receive and display the rates from up to four shore stations simultaneously. This gives the operator the ability to select any two rates for range-range control and switch from one chain to another with relative ease. The hydroplot system was able to accept and print out only two rates during this project. In order to record the four rates, a Hewlett-Packard Thermal Recorder was connected directly to the Argo system. The thermal printer would then record up to four rates and the time in conjunction with the hydroplot system. As with all systems of this type, each new chain must have a beginning and closing calibration to ensure that there were no lane losses. The Raydist shipboard receiver will receive only two ranges at any one time; in fact, only two shore stations can be on the

air simultaneously. Any additional stations transmitting on the same frequency will interfere with these stations. This means that when the time to switch from one chain to another occurs, one station has to be turned off before the next station can be turned on. This compounds the calibration and shore-based logistic support problems.

2. Another advantage of receiving the four rates simultaneously is that whenever it is possible, they can all be calibrated at one time. If there is any question as to the reliability of any fixes obtained from the two stations being used, an inverse distance from the position obtained can be computed to a third station being received. These figures can be compared, and any major problems identified.

3. The following calibration technique is possible when three or four signals are being received. The pair being used for control is calibrated using standard techniques. When the ship reaches an area where all four signals are received without interference and just before leaving the usable work area of the initial pair that have been calibrated, the ship will determine the exact lane values of the second pair. The second pair will be corrected at this time, and the vessel will begin using them for control. This pair will be calibrated using standard techniques when the ship reaches a suitable area. This calibration will verify the lane values and provide correctors as required. There will be times when only three Argo shore stations will be received simultaneously. The ship will then switch from only one station to another to change the control net. This technique can eliminate the need to dead-head from the working area and back to recalibrate when switching from one range-range net to another.

4. Adequate range (90-100 miles over salt water and 50-60 miles over fresh water) to the ship usually can be obtained by using 35-foot whip antennas at the shore stations. Since numerous shore stations are required, this is a highly desireable feature. Two men can tear down, move, and set up a new station with relative ease in 1 day providing the transit time between stations is not over 2 or 3 hours.

Both Argo and Raydist shore stations are compact and can be housed in a wooden shelter about 4' X 4' X 4'. Raydist operates on two 12-volt batteries which are charged by a small trickle charger. The trickle charger requires a 110-volt outlet. Argo operates directly from the 110-volt power which is converted to d.c. on two 12-volt batteries.

Since I was involved with the PEIRCE's Lake Huron Project as project manager, and Argo was the primary horizontal positioning system, the remainder of this report will outline procedures used and recommendations for future projects of this type.

Horizontal control for Argo positioning stations and calibration was established by AMC Operations personnel about 1 month prior to the ship's arrival in Port Huron to begin this project. A total of nine Argo station sites were required for adequate range-range control to cover this project. Different pairs were used to obtain a minimum of 30° intersection angles by "leap-frogging" the stations as each new range-range chain was required. In

addition, Del-Norte range-range and range-azimuth control was used in certain areas near Port Huron, Cheboygen, and the Strait of Mackinac. The Argo was calibrated by taking two T-2 theodolite cuts from existing third order traverse stations simultaneously or by observing three Del-Norte rates from third-order traverse stations or a combination of both. Only two rates can be received with the Del Norte being used; therefore, in order to receive three rates, two Distance Measuring Units (DMU) and two master Transmitter/Receivers (T/R) are required on the ship. The T-2 theodolite cuts appeared to give the best results. The Del-Norte calibration was used when visibility or other conditions precluded T-2 visual calibration. By using three rates, a check on the Del-Norte accuracy was determined. Due to the lack of natural objects with third order control, the ship was unable to use three-point fix visual calibration.

The shore-based support unit consisted of one Argo technician, three U.S. Coast Guard personnel, two PEIRCE personnel, one AMC Rotating Cartographic Technician, and the project manager. All of the nine Argo shore station ground plane wires had been installed prior to the beginning of the project which enabled a station to be moved and set-up in a minimum amount of time. A total of four complete shore stations were available for this project which enabled three to be on the air at any time while the fourth station was being moved to a new location. The Argo technician and one or two U.S. Coast Guard personnel would set up the new station, and two of the PEIRCE personnel would tear down and move the station when the ship was finished with it. In the meantime, the two field personnel would take T-2 cuts to the ship and/or set up Del-Norte for calibration or primary control. At times, the other two PEIRCE personnel would assist in setting up Del-Norte control stations. No major problems were encountered in moving the stations when required or setting up for calibration.

Good communication with the ship between all the shore units was critical. In this respect, the radios provided by the U.S. Coast Guard were not quite powerful enough. There were times when we had to rely on passing messages through the nearest U.S. Coast Guard stations or by phone patch through the radio in Operations at AMC. Also, the U.S. Coast Guard stations were not well enough informed in advance about our activities, which caused some minor problems.

For all future projects such as this, it is recommended that the U.S. Coast Guard District Commander or an appropriate U.S. Coast Guard representative write letters to all U.S. Coast Guard stations in the area advising them of the project and arrange for limited assistance to the project if it is required. The radios provided the shore parties should be powerful enough to reach at least 50 miles, and arrangements should be made to have a special channel designated for use. It would be most desirable to have the capability of several channels, such as 16, 22, 23, 81, and 82.

It seemed to take longer than necessary to obtain calibration results from the computer on board the PEIRCE. In order to speed up the calibration procedures, programs have been written for the HP 9815A calculator that can be used in place of using the PDP8. This allows the computer plotter system to remain on line while the ship is calibrating. All the necessary programs (three-point fix, T-2 cuts to the ship, three range Del-Norte, etc.) are on

cassettes and can be loaded into the calculator in a matter of seconds. The field data (all necessary G.P.'s) are loaded as a signal tape on one of the cassettes. Signals being used for calibration are entered into the calculator by number; the horizontal angles are entered plus any other pertinent data in a matter of about 1 or 2 minutes, and the answer is printed out on tape in a matter of seconds. More detailed information on the programs is available from AMC Operations. The programs were written by Commander Ludvik Pfeifer and are presently in the process of being documented.

Lake Huron presented problems that would not be encountered with a survey along the east coast. The main problem is that Lake Huron is fresh water, and systems such as Argo will transmit approximately one-half the distance over fresh water as over salt water (the exact distance was not known). We found that about 50 to 60 nautical miles is the maximum daytime range. Sky wave conditions at night can reduce the operating range to 30 to 40 miles. The worst sky wave effect is at sunset and sunrise, and the amount is not constant. One night the effect is minimal, and the next night the range might be reduced to 30 miles.

There was some question as to what value should be used for the propagation velocity over fresh water for Argo or similar type systems. Tests had been conducted by the Canadian Hydrographic Survey and the NOAA Ship MT. MITCHELL in 1977 to determine the value. The Canadian values were 299,425 km/sec and 299,500 km/sec. The MT. MITCHELL's values were 299,299.49 km/sec and 299,410.29 km/sec. Since four different values were obtained in 1977, it was determined that some time should be spent, on a not-to-interfere basis, to determine the propagation velocity value during this project. The procedure used was as follows:

The Argo was calibrated with T-2 theodolite cuts to the ship's Argo antenna from third order horizontal control stations about 2 miles from shore Station #12; then the ship ran a straight line on a constant bearing to a point about 50 miles from this station where the Argo was again calibrated using theodolite cuts. The signal from the shore station to the ship was completely over water, and by observing the strip chart recordings it was determined that no lane losses were encountered between calibrations. By computing an inverse distance between the calibration point 2 miles from Station #12 and the final calibration point 50 miles from this station, the actual distance between the two calibration points can be determined.

This distance is compared with the distance obtained with Argo by converting the Argo lane values to meters. Prior to starting the run between the two calibration points, the value of one Argo lane is determined by dividing the value of the velocity of propagation over salt water (299,670 km/sec) by two times the Argo frequency being used (using a frequency of 1648, one lane = 90.919296 meters). After calibrating 50 miles from Station #12, it is found that the Argo lane values show the distance between the two points as 79,974.62 meters, while the computed inverse distance showed the distance as 79,954.60 meters. This indicates that the wrong velocity propagation value (299,670 km/sec) was used. To find the correct value, divide the computed inverse distance by the distance obtained by Argo and multiply this figure times the velocity propagation used. An example is as follows:

Velocity of propagation used = VP (299,670 km/sec)

Computed inverse distance in meters = ID (79,954.60 meters)

Distance determined by Argo = AD (79,974.62 meters)

$$\frac{ID}{AD} \times VP = \text{Correct velocity of propagation } (299{,}595)$$

Two items are critical when determining this value; the beginning and ending calibration must be very precise, and the signal to the ship from the Argo station must be completely over water. It was found that observing the shipboard Argo antenna from two third-order or better horizontal control stations simultaneously with T-2 theodolites gave the best calibration results. The horizontal control stations need not be intervisible, but the azimuth or initial used from the station must be third order or better. In order to verify the accuracy of the value obtained, the test should be conducted at least twice and preferably three times.

One other area of this project that should be remembered is to correlate the WGS 72 horizontal position data with the NAD 1927 horizontal position data. The Loran-C station positions are on the WGS 72 datum, and Argo stations were on the NAD 1927 datum. The difference between the two datums can be requested in advance from geodesy and the data available at the beginning of the project.

The required position accuracy of 50 meters was obtained on this project. Position data were acquired during the period June 6 to June 14, 1979. One thousand three hundred ninety-five positions were obtained on 865 nautical miles of trackline.

The U.S. Coast Guard has requested the National Ocean Survey to conduct another survey of Lake Huron in 1980 for the purpose of calibrating a new Loran-C chain recently put into use. It is planned that the NOAA Ship WHITING will conduct this survey in July 1980, using basically the same techniques outlined in this paper.

DISCUSSION

Lt. Chelgren: I was the Operations Officer aboard ship at the time, and I have just a couple of comments about the baseline method. The problem I found in theory was when a person is adding in the landpath distortion with the velocity difference he has to be able to separate those two to get an accurate velocity propagation. What we did, in essence, finally, was to calibrate near one station, and then when we calibrated another time, it was on approximately the same azimuth, which was very necessary for maintaining the same landpath distortion, on the other side of the lake. And we took the actual lanes crossed, divided by two, and divided that into the inverse differences, the inverses being the station calibration site inverses. And if you multiply that times the frequency, you come out with an actual velocity propagation. It's an alternative method of looking at the velocity propagation. His would be as a correction method, and the way that I devised for the project was just as a straight computation. And the method of setting one Argo pair off the other, I have a lot of complaints about that, although I see you're

going to still try and do it next year.

Mr. Shea: We hope that by discussing this project and the methods used, we can arrive at some solution to the problems encountered.

Lt. Chelgren: Yes.

Mr. Shea: Since I was on the beach coordinating our activities and not on the ship, I was not aware of all the problems you were having.

Lt. Chelgren: The main problem we had was with lane jumps. When monitoring all four stations, generally two of the four stations have such great landpath distortion that there is bound to be such terrible signal attenuation that there are going to be lane jumps all over the place. When one pair is set off the other some pairs may or may not have more landpath than in the operating area for which they are going to be used. I just didn't find it totally adequate. It resulted in many extra processing hours, and if we hadn't had that thermal printer on board, of course, about two-thirds of the data, three-quarters of the data, would have been lost entirely, using this method of setting one pair of Argo stations off the other. It adds extra processing time when you do experience lane jumps. If you're going to be operating using the same tracklines, next year on Lake Huron, you're going to experience many lane jumps.

Mr. Shea: Well, this is what we hope to bring out. We won't make the same mistakes we made last year. Is there any possibility we're going to have the capability of getting four rates into the computer system? Does anybody know about this?

Mr. Wallace: We can get four in right now. The problem is to modify the format to output more than two, and of course what happens, if you modify your raw data tape, you modify the program that reads the raw data tape for post-processing. I think we're going to discuss that this week, though, are we not, with the U.S. Coast Guard?

Mr. Shea: Yes, we plan to.

Mr. Wallace: It's a software change; we made new cables to get the data into it, but someone has to modify the software in order to do something with it. And of course, we'd only be doing something with two at a time, right now, as opposed to more than two.

Mr. Shea: Oh, one other thing I forgot to mention. We used the PDP8 for calibration; and we're thinking of, in fact, we have some programs now that we can use on a 9815-A Hewlett-Packard calculator that will do the same thing. We're going to see if it will work as well as the PDP8, which would allow a person to keep the PDP8 on line all the time. Commander Vik Pfeifer has written some excellent programs for the 9815-A for calibration, taking into account all types of calibration. We have those at AMC now, and we're having them documented, so if anybody would be interested in information, we'd be glad to give it to them.

Lt. Cdr. Floyd: I've had experience with Raydist and we never had any problem with the propagation rate that I can recall. Now, the problem with Argo, is that it's never been determined that well, or does it vary with time?

Mr. Shea: The problem is that it's different over fresh water and salt water with any of the medium range systems such as Argo. You have the same problem with Raydist, the same problem with hydrotrack, or similar systems. It's just, for any similar system the propagation value over salt water is different, and we were just trying to find some method or procedure that we think is foolproof, as foolproof as possible, to determine what the value is.

NAVBOX - STRAIGHT LINE NAVIGATION AND ON-LINE DATA FILTERING ON HYDROGRAPHIC SURVEYS IN CANADA

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Canadian Hydrographic Service
Burlington, Ontario

ABSTRACT. The Canadian Hydrographic Service began in the mid-sixties to investigate methods to provide computer assistance to hydrographers that were using conventional data collection techniques. NAVBOX, the fifth generation product of these investigations, provides straight line navigation from a variety of positioning systems. Before being accepted, positions and depths are passed through NAVBOX software filters. Used first onboard helicopters and tracked vehicles in the Arctic, NAVBOX has been used on conventional hydrographic surveys since 1977. It has many real and potential survey applications.

INTRODUCTION

The Canadian Hydrographic Service in the mid-sixties began to consider methods of automating Canadian hydrographic surveys. In 1968 HYPOS, Hydrographic Position, was developed and used until 1973 with some success. Survey data were collected in the conventional manner; however, sounding rolls were mailed to a central processing station where soundings were scaled with a digitizer and merged by computer with telex-transmitted positions. In as little as 2 weeks, the sounding rolls, printout, and sounding plot were again in the hands of the field hydrographer. The hydrographer had to find the mistakes, edit the data, and redo the whole process. Not impossible, except the computer wizards were having difficulty making friends with the hydrographers, who saw a rise in the processing time, the ratio of bad to good data, and the number of personnel for the job. The hydrographer did not see some of the benefits. Computer programs were developed to convert electronic positions, to plot soundings, to edit data, and to produce field sheets. However, the best was that the hydrographers began to lift their sights to the possibilities of technology improving what some thought had been perfected.

As challenging as HYPOS might have been, it was not working satisfactorily. So, in 1969, with the philosophy that if you cannot bring the hydrographer to the mountain, you can bring the mountain to the hydrographer, computers were introduced to the field with HAAPS, Hydrographic Acquisition and Processing System. Depths and positions were converted from analog to digital form onboard the survey vessel, stored on paper tape (later magnetic tape), and processed off-line with a PDP-8 computer. This system had many advantages. There was short turn-around time, because the computer was in

the field. The software needed to process the data was developed by hydrographers for hydrographers. Soundings were selected, stored, and plotted from a digital source in the field. Sounds good? Sounds great, but still more problems. The recorded data were unverified, so the hydrographer remained unaware of any logging difficulties until the computer processed the data. Often by then it was too late, because days may have passed without the problem being noticed, requiring either resounding of large areas or manual recovery of the data.

That is why in 1974 INDAPS, The Integrated Navigation, Data Acquisition and Processing System, was developed. For the first time a computer became part of the logging system and real-time data verification and equipment checks were possible. Besides providing more reliable data, the computer logger provided a certain flexibility and versatility. The hydrographer could tell exactly where he was and in what direction he was going. If the hydrographer told the computer where he wanted to be and in which direction he wanted to go, the computer could provide steering instructions to get the hydrographer on-line and keep him there. Enter the black box syndrome. Was the hydrographer relying too heavily on something he did not completely understand? Was he being turned into a button pusher? Some thought so. However, the computer wizards were slowly making friends with a few hydrographers who were beginning to see some real benefits from this development.

As good as INDAPS was, it still had problems. Its size, weight, and high power requirement were not suitable for a small launch. So several enterprising engineers designed PHAS, a Portable Hydrographic Acquisition System. It was small, light weight, easy-to-use, and had a low power requirement. Since it was computer-based, it performed data checks on depths and positions. But it had no printer, an inadequate data display, and no way to navigate. Where does this lead?

It led to NAVBOX.

NAVBOX

Because PHAS did not navigate; because INDAPS was bulky, heavy, and needed lots of power; because HAAPS had no on-board computer to check data, and because HYPOS was so clumsy and cumbersome; INDAS, the Integrated Navigation and Data Acquisition System (NAVBOX's proper name), was designed in the fall of 1976 and implemented in the spring of 1977. The box has three circuit boards: an SBC80-10 INTEL single board computer, a North Star Computer floating point arithmetic board, and a custom designed board, which contains a video display controller, a clock, additional memory, and peripheral interfaces. The other major components are a 6-column thermal printer, a 16-character keyboard, and a 5-inch TV monitor. The total package weighs 30 pounds, draws 3 amps at 24 volts, is inexpensive, and is easy-to-use.

The software can handle hyperbolic positions from systems like Seafix or Minifix, or range-range positions from the Motorola Mini-Ranger and RPS or from Trisponder. The NAVBOX can operate as a stand-alone navigation unit, directing survey vessels along lines or between points with no depth input

and no data logging, or it can log position and depth without navigating, or it can log and navigate.

NAVBOX SOFTWARE

Straight Line Navigation

For many reasons, hydrographers prefer to run straight lines instead of following lines of constant radio position. First, and most importantly, survey planning is much easier. Instead of worrying about which pattern has to be run so that depth contours will be crossed instead of followed, or worrying about manually conning the vessel to keep on a straight line, a problem compounded by rough seas, winds, and currents, the hydrographer need only worry about the direction of his survey line, the point to start the first line, and the distance between lines. The NAVBOX (with a little help) will perform the rest. Second, because of better planning, the survey becomes more efficient. In St. Lawrence River tests, 30 percent fewer sounding miles were run using computer-assisted, straight line navigation in an area previously controlled by lines of position. A 10-percent reduction can generally be realized. Third, the coxswain has an easier time keeping the vessel on line, and the hydrographer is freed from his conning chores and is able to better plan the immediate survey.

The mathematical solution to the problem of line-keeping is found in analytic geometry. By defining the line to be run as an X, Y coordinate on the line and a heading, and by substituting the position of the vessel (X_p, Y_p) in the straight line equation, the distance off line and the direction to steer to get back on line can be computed. Then for each second, the time, pattern readings, northing and easting, distance off line, direction to steer, and depth are displayed for the hydrographer on the NAVBOX TV monitor and for the coxswain on a remote monitor. Line reversal is a push-button operation from the front panel, and line spacing is a user-entered variable.

The general form of the straight line equation is:

$$AX + BY + C = 0$$

where:

A = cos h

B = -sin h

C = a constant equal to but opposite in sign to AX + BY to balance the equation

X = easting of a point on the line

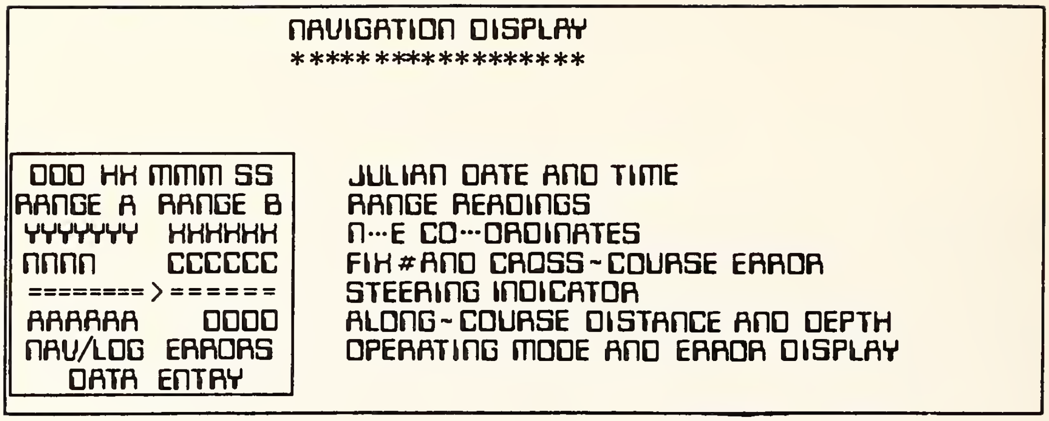

Figure 1.--NAVBOX navigation display.

Y = northing of the same point on the line

h = heading of first sounding line

If (X_p, Y_p), the present position of the vessel, is substituted in the line equation to replace (X,Y), the result will be the distance off line. A negative value indicates the vessel is too far to port, so it must be brought to starboard to be back on line.

As can be seen from plane trigonometry, when the line direction is reversed, the sign of both the sine and cosine is reversed.

A becomes -A

B becomes -B

If the line spacing is incremented, X and Y are recomputed.

$$\Delta X = \text{line spacing} * A$$

$$\Delta Y = \text{line spacing} * B$$

$$\text{new } X = \text{old } X + \Delta X$$

$$\text{new } Y = \text{old } Y + \Delta Y$$

A new value for C must also be computed, and the sign of the line spacing changed for the next line.

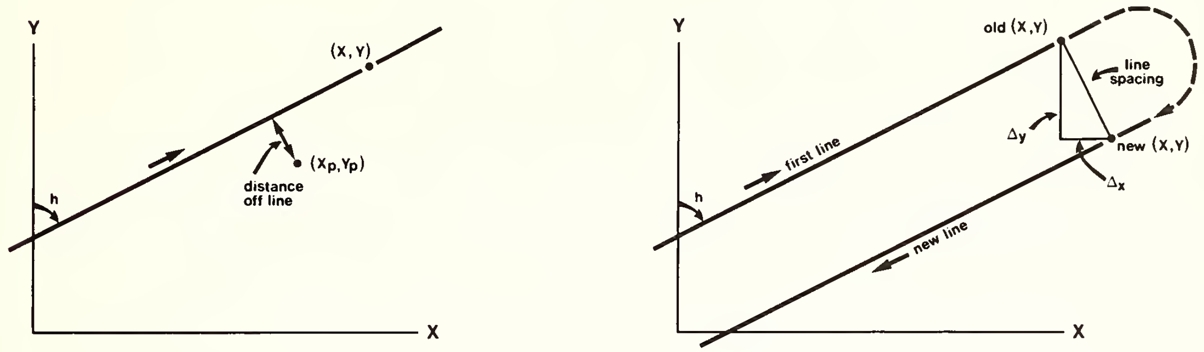

Figure 2.--Mathematical solution to the problem of line-keeping.

Depth Filter

Now that the hydrographer is on line (in one sense at least), he is extremely interested in collecting reliable data. To help ensure that recorded depths and positions are clean, software filters are used in the NAVBOX to reduce the amount of bad data. Depths and ranges are filtered by using a gating technique. The gate width is defined as the absolute acceptable difference between two successive values. The gate is set up around the previously accepted value. The current value will pass through the gate if it does not vary from the previous value by more than the gate width.

How does the depth gating technique work? Each depth received is checked against a user-defined minimum depth. This is useful, for instance, if aeration is a problem during turns or rough seas, or if transmission noise is present. A minimum depth check is necessary, since sustained bad depths may eventually be accepted by the filter. Depths less than the minimum depth are discarded.

A permanent gate is symmetrically established around a good depth. A new depth is compared to the gate limits, and if it falls within the gate, the permanent gate is re-established around the new depth. If the new depth is outside the limits of the gate, a temporary gate using the same gate parameters is set up around the depth. If the next depth is within the permanent gate, the depth inside the temporary gate is discarded. If, however, the next depth is inside the temporary gate, the temporary gate is re-

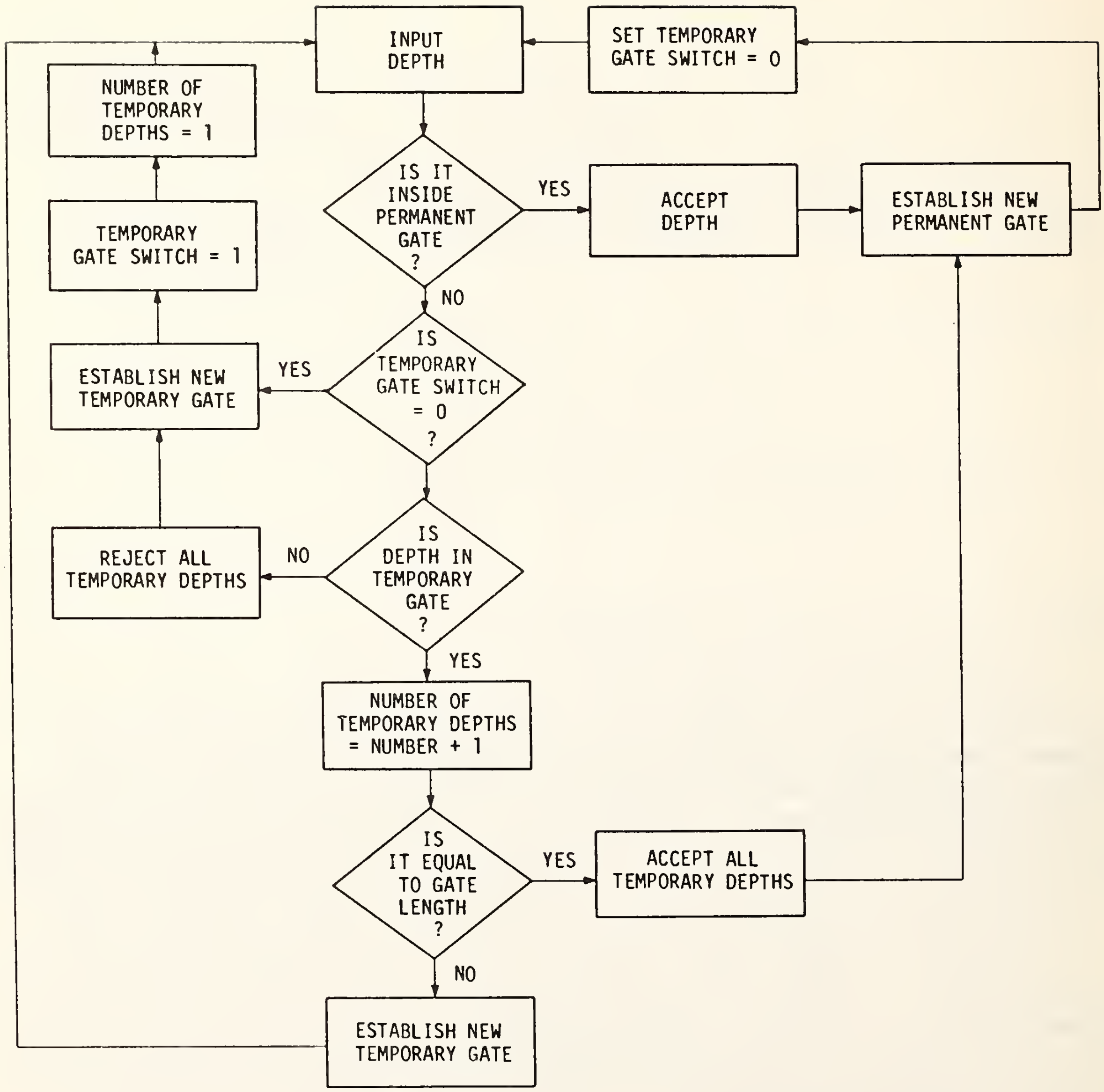

Figure 3.--Depth tracking gate.

established around the depth. If the number of depths through the temporary gate is equal to the user-defined gate length, the temporary depths are accepted, and the permanent gate is redefined around the last depth inside the temporary gate. Each second the shallowest good depth is recorded.

The gate is initialized by establishing a temporary gate around a number equal to the minimum depth plus 1 decimeter. When the first depth is read, the temporary gate will be redefined, and if the data are good, a permanent gate will eventually be set up.

The values used for gate width and gate length are important. If the gate is too narrow, bottom detail may be ignored; if the gate is too wide, bad data may be accepted. The gating technique does not work well on a steep slope where each succeeding depth is out-of-gate, and none are selected. This can be solved by expanding the gate width, but this could allow bad depths to be accepted.

Position Filter

If the depth filter is used correctly, the hydrographer will record good data, or at least we hope so. But they are useful to him only if his positions are reliable. In the Canadian Hydrographic Service there are mainly two problem areas.

On continuous wave, phase comparison systems, such as Seafix or Minifix, weak signals or atmospheric and RF interference can cause lane jumps. Receivers are set at a reference buoy before sounding operations begin, and are checked any time interference is suspected and at the end of each work day. This may mean the survey vessel steams several miles to a reference point each time a positioning problem is suspected, losing survey time. If a pattern change goes undetected until the end-of-day check, it may result in that day's work being repeated on the following day.

Except for system calibration and phase shifts, the pattern reading is correct as long as the signals are phase-locked. After calibration, the readings may vary with phase shifts which can be caused by changes in temperature, humidity, or atmospheric conditions, but these shifts are monitored throughout the survey and corrections are applied to pattern readings. Essentially, the only error check required for this type of positioning system is to detect when the receiver has lost lock with one or more of the shore stations.

How does the NAVBOX microprocessor check for lost-lock conditions? Pattern readings for 1 second are averaged and compared to the average of the previous second. If the difference exceeds the distance the vessel can travel in 1 second, an alarm is triggered. This distance, in portions of a lane on the baseline, is a variable entered by the hydrographer. Bad pattern values are set to zero for recording, the last good pattern reading is printed out, and subsequent bad values are printed until no additional lane jumps are detected. If the period of pattern instability is short, the pattern value can be reset by using the printed values to derive a lane

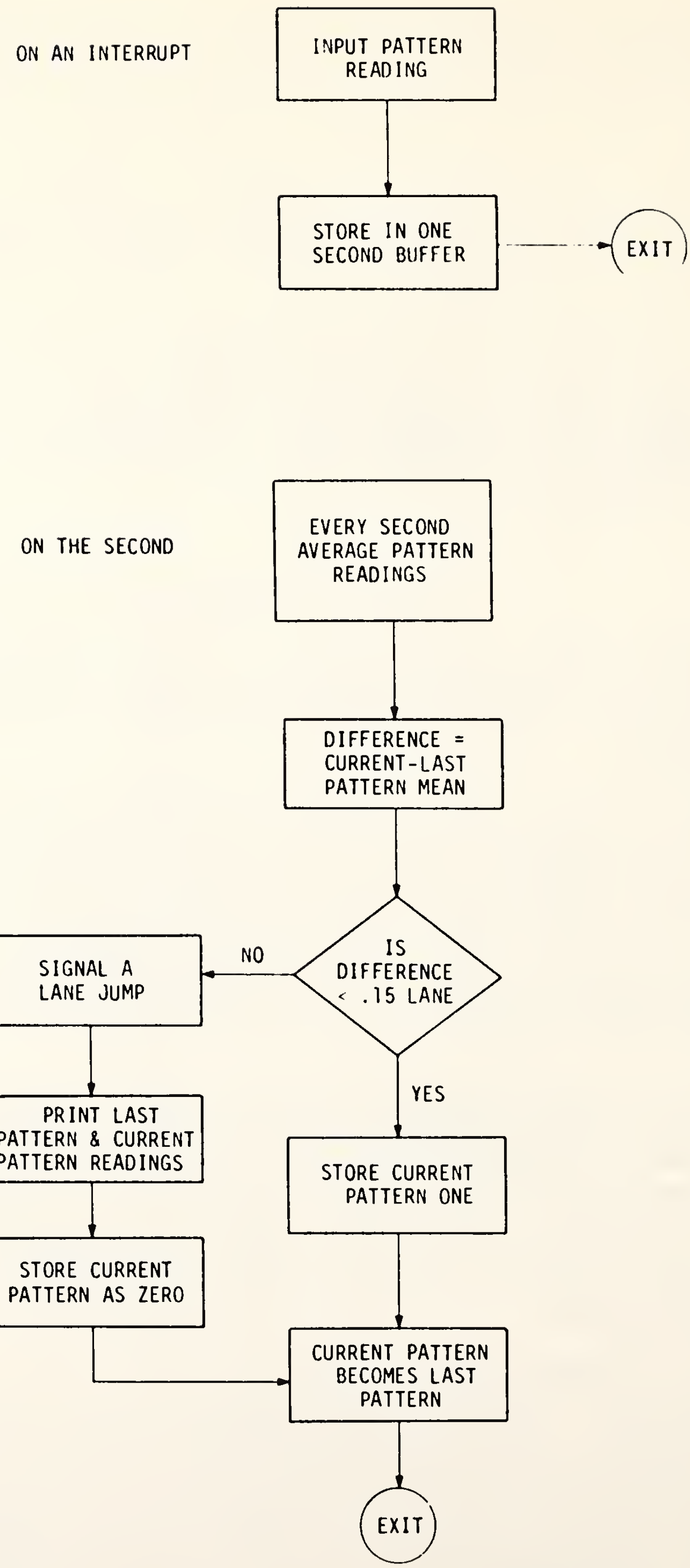

Figure 4.--Lane jump detector.

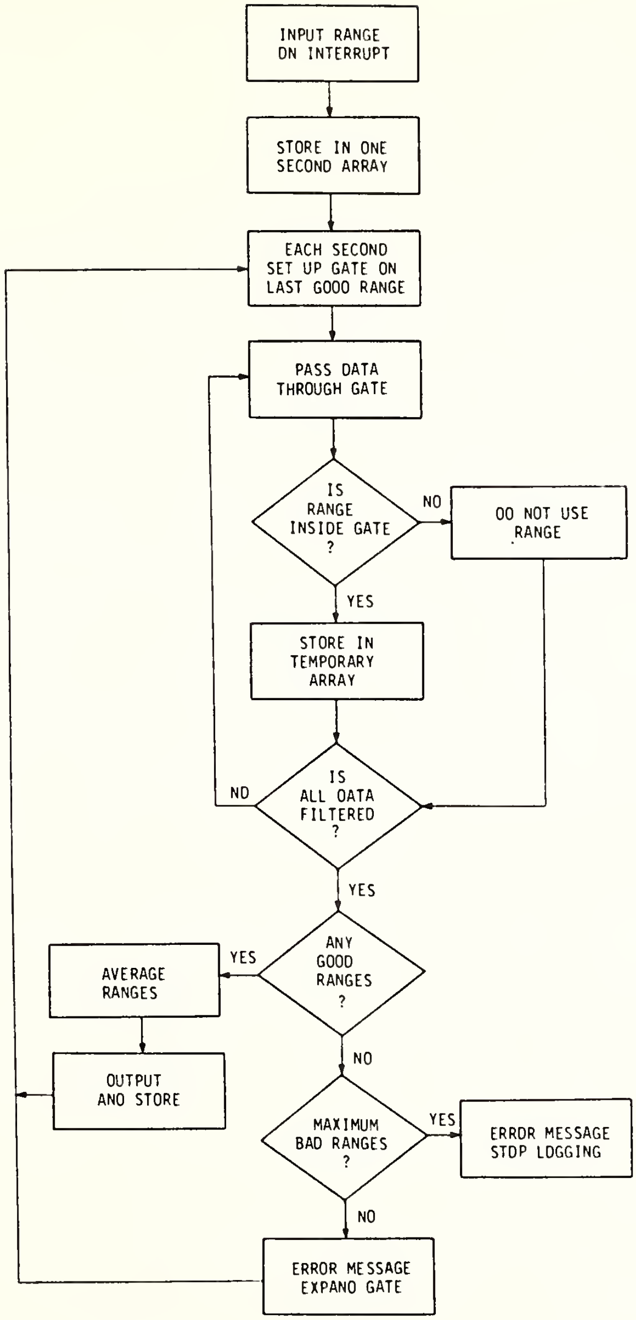

Figure 5.--Range/range position filter.

correction. This saves a long voyage to a reference point. The software filter is also a good indicator of pattern stability. However, the hydrographer may tend to expand the filter parameter until the filter ignores the jitter caused by faulty cables, antennas, transmitters, or receivers while lane jumps are still detected. This is not a recommended practice, since unstable patterns means a fault needs to be repaired.

Systems that operate on the basic principle of pulse radar, such as Motorola RPS and Mini-Ranger, can produce range jumps of ± 4 meters at a stationary receiver. The ranges, which can be affected by signal reflections and cancellations, are filtered by the NAVBOX. Each distance received during 1 second is stored in a temporary buffer. A symmetrical gate is established around the average of the good ranges acquired during the previous second, and distances within the gate limits are averaged. The gate width is based on the maximum distance the survey vessel can travel in 1 second. If none of the distances are within the gate, the gate is expanded by an amount proportional to the rate of change of the range. If the range is not reacquired within the user-defined maximum time, known as gate length, an alarm is activated. Once again, gate values are important. If the gate is too narrow, good ranges will be expelled, and the NAVBOX will not navigate. If the gate is too wide, excessive range instability will be unnoticed.

Why are the depth filter and range filter algorithms different? As the launch moves in a straight line, the ranges increase or decrease at a predictable rate. If no acceptable data are available for 1 second, it makes sense to expand the gate by the same rate, though a limit on the number of times the gate may be expanded is required to ensure that the NAVBOX does not accept bad ranges, but instead informs the hydrographer that good ranges must be reacquired.

However, depths do not behave in the same manner. They may remain constant on a flat bottom, change gradually or abruptly on a rough bottom, but they seldom change at a constant rate. Gate expansion, then, is not a logical depth filter parameter. The temporary gate technique is introduced so that the permanent gate will not be forsaken until a reasonable number of depths are found out-of-gate.

NAVBOX APPLICATIONS

The NAVBOX has many real and potential applications. To the hydrographer, the most important is to run survey lines. Survey lines run with NAVBOX can be run in any direction, parallel and straight, planned easily, surveyed more efficiently, and modified easily any time during the work day.

The NAVBOX can guide the survey vessel to the survey area and home again. The hydrographer simply enters the vessel's present position and its destination. NAVBOX indicates in which direction to travel, keeps the user on line, and tells the user when he has arrived. This is the perfect opportunity to run check lines, and it is extremely useful when visibility deteriorates.

In point to point operation, the NAVBOX guides the vessel between predetermined points along predetermined lines. This is useful when performing

bottle casts, collecting bottom samples, or conducting similar scientific projects. It is used in the Arctic where spot soundings are required at regular intervals over ice-covered waters. In another version of the point to point mode, a number of points may be entered and stored in memory. As each point is recalled (a push button operation), the NAVBOX indicates the direction to steer and distance to travel, then guides the vessel to that point. This is very useful during shoal examinations, if the coordinates of each shoal indication to be examined are entered. Once the peak of the shoal has been determined, it is a simple matter with the NAVBOX to run a tight grid pattern over the shoal to delineate the shape.

The NAVBOX is potentially useful to dredging contractors for line-keeping, or to surveyors for checking the work of dredging contractors. It can be used for line-keeping during side scan sonar or sweep surveys, where the grid pattern is extremely important, or it could be used for line-keeping during the installation of submarine pipelines and cables.

However, it need not be restricted to straight line applications. Drogue positions, during a current survey, for instance, could easily be logged on the NAVBOX, or it can simply tell the user his position.

As you can see, NAVBOX can be a versatile instrument, limited only by the ingenuity of the user. In addition, if it does not perform the required operation, software changes are possible. These could include changes to convert positions to latitude and longitude instead of grid coordinates, or changes to accept other types of positioning systems.

CONCLUSION

The NAVBOX has been used in a production capacity since its inception in 1977. It has been used in the Arctic on tracked vehicles and helicopters where bitter cold and excessive vibration did not inhibit its performance. The NAVBOX has been used onboard hydrographic and geolimnological survey vessels from Lake Erie to Lake Huron, from Georgian Bay to Lake Nipissing.

As part of a Canadian Government program to transfer technology to the private sector, NAVBOX units are being produced commercially in Canada. Private and public survey organizations and dredging contractors have shown a large interest in NAVBOX both nationally and internationally.

Are the computer wizards and hydrographers friends yet? Well, more or less. A few hydrographers may be inclined to rely on the tried and true methods, and not completely trust the computer-generated figures (sometimes with good reason); most hydrographers feel there is a need for systems like NAVBOX and lend their support to similar projects.

I would like to thank the conference organizers for inviting the Canadian Hydrographic Service to participate. It has been an excellent opportunity for hydrographers within the service, who did not help design NAVBOX software filters, to critically review the range gate, depth gate, and navigation algorithms. As a result of this exercise, a flaw in the

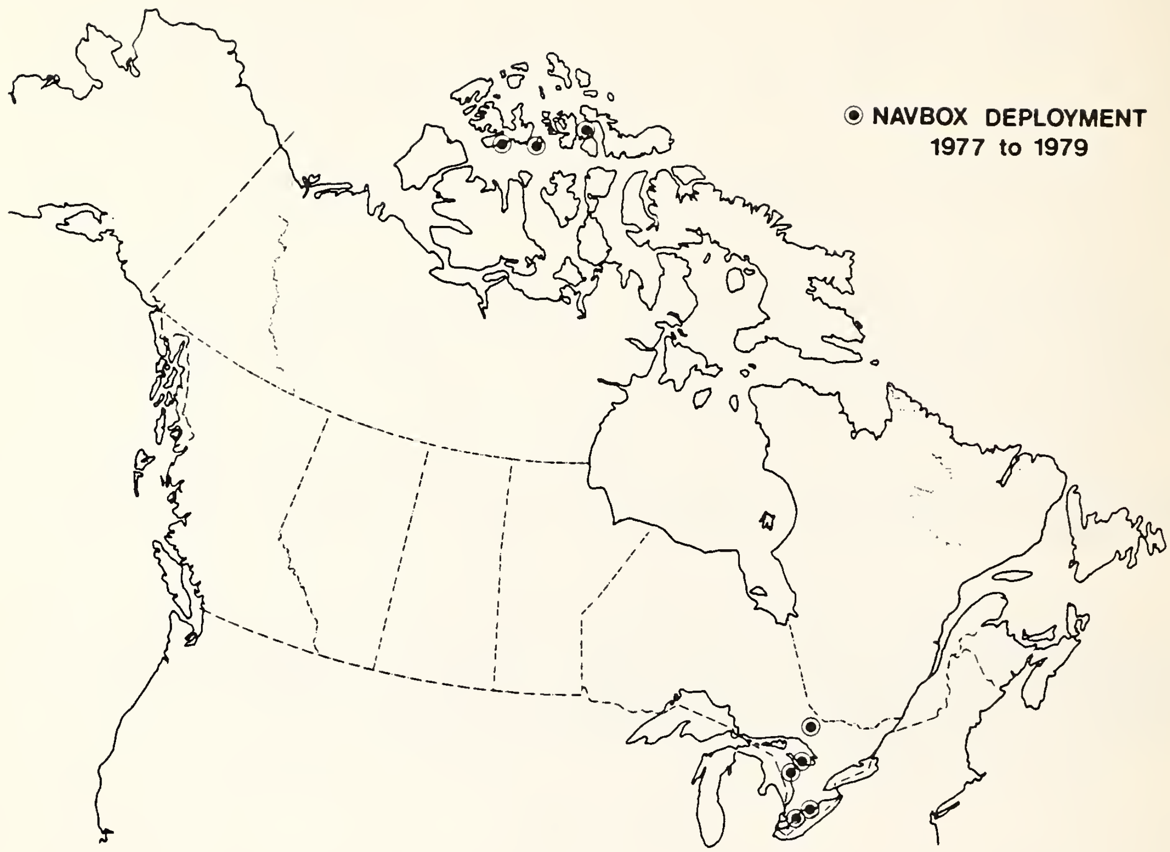

Figure 6.--NAVBOX deployment.

range gate algorithm was discovered. The gate works perfectly when the receiver is stationary, but inadequately when the receiver is on a moving platform. This problem will be rectified this summer. Under critical scrutiny the depth gate appears to be adequate but not flawless. Data errors, though less frequent, are still possible. The software will not be modified, but hydrographers who use the system will be made aware of the limitations. Upon review, the navigation routines seem to work perfectly.

Is there a cure for the black box syndrome? If hydrographers become involved directly in the design and implementation of new systems that are being developed specifically for their use, it will help to remove some of

the mystique surrounding development projects. Every hydrographer must ensure that he completely understands the capabilities and limitations of a system before he uses it. More importantly, the hydrographer should have a thorough knowledge of how to do the job without special equipment. There are a few hydrographers that view straight line navigation without NAVBOX as incredible if not almost impossible. However, no system, not even the NAVBOX is foolproof.

DISCUSSION

Mr. Wallace: What do you do if you have bad range data, or bad lane data? Under your XY solution, if you get a bad range value, obviously you can't compute an intersection. What do you do with the steering indicator?

Mr. Macdonald: If we get a bad range and we can't compute XY, we set the XY values to zero for that particular second. If we don't acquire them within the length of the range gate, if we don't reacquire good ranges within a certain length of time, we stop navigating and tell the operator.

Mr. Wallace: What would be a typical period of time that you would allow it to continue--go off looking for good ranges?

Mr. Macdonald: I think the system defaults to 10 seconds, but again, it can be set to any value by a hydrographer.

Mr. Wallace: What output media do you record the data on, such as paper tape, mag tape?

Mr. Macdonald: Yes, the NAVBOX--used as a stand-alone unit--doesn't have any recording media, except the paper printout. But it has the capability to record on tape, or any other recording media you may wish to use. We have been using it with magnetic tape cartridges, though they haven't been as successful as we'd like.

BIONAV--THE BEDFORD INSTITUTE OF OCEANOGRAPHY INTEGRATED NAVIGATION SYSTEM

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ABSTRACT. The Bedford Institute of Oceanography Integrated Navigation System (BIONAV) has been operational for more than a year and is now installed on three Canadian Government survey ships. A slightly modified version was operated for 2 months at the North Pole as part of the LOREX project. BIONAV combines Transit Satellite Navigation, passive ranging Loran-C, and ship's log and gyro by means of a number of user-written FORTRAN routines operating under the Hewlett-Packard real-time executive operating system. It has proved to be reliable and simple to operate, the two primary design goals, while also being flexible and more accurate. We have compared it with an acoustic navigation system and will compare it with an inertial navigation system early in 1980. We are now adding improvements that were suggested during its first major operational field season, including these new features: skywave Loran-C, fixing by log/gyro and a single Loran-C range, Decca, propeller RPM,and rudder angle and output to an XY plotter.

INTRODUCTION

In late 1975 we asked about 80 hydrographers, geoscientists, oceanographers, and technical support staff at the Bedford Institute of Oceanography (BIO) to help specify the design goals for BIONAV (Bedford Institute of Oceanography Integrated Navigation System). Above all, they said BIONAV should be reliable and simple to operate. They also said BIONAV should:

- Present real-time navigational data in a form that the navigator and scientist could most conveniently use
- Allow component navigation systems to function independently of BIONAV
- Use existing equipment
- Be capable of easily adding, deleting, and switching sensors
- Improve the navigational accuracy then achievable
- Provide new capabilities (e.g., real-time estimated ocean current vector)

- Be capable of continually evolving, but with annual changes small enough to avoid extensive retraining of operators

- Be capable of being moved from ship to ship or into a standard-sized shipping container

BIONAV is analogous in many respects to the Bathymetric Swath Survey System (BS^3) (Hopkins and Mobley 1978); but, whereas BS^3 concentrates on the production of real-time bathymetric contour maps in the near shore area by means of the Bo'sun multibeam sonar, the emphasis in BIONAV is on the production of reliable, real-time navigational information, primarily in the offshore zone.

The BIONAV system hardware is centered around the HP 2100 computer, which was part of our Canadian Marconi Company (CMC) Transit Satellite Navigation (Satnav) Systems. The CMC Satnav systems consisted of a 16K HP 2100 computer interfaced to a Satnav receiver, a terminal, paper tape reader, video display, and ship's log and gyro. To convert to BIONAV we enhanced the computer by increasing the memory to the 32K maximum, added an HP 7900 moving head disk, and installed the Hewlett-Packard Real Time Executive (RTE) II operating system. We retained all the original CMC interfaces and added interfaces to another terminal, a 9-track magnetic tape unit, an Austron passive ranging (rho-rho) Loran-C system, and a link to a general purpose computer. About 85 percent of the hardware in the present BIONAV systems existed prior to the start of the project. Figure 1 shows a standard BIONAV system.

The log, gyro, and Loran-C systems operate independently of BIONAV, but we can revert to the original CMC Satnav system software within about 15 minutes, if necessary.

Other devices that we have interfaced to BIONAV in the past include:

- Omega receiver

- Mini-Ranger--via the General Purpose Interface Bus (GPIB-IEEE 488)

- PHAS (Portable Hydrographic Acquisition System)

- Floppy disks

- Link to a special BIONAV microprocessor unit (MPU) (via GPIB and RS-232) which acquired data from Decca, propellor RPM, and rudder angle

- Magnetic tape cassette recorder

The symbiotic relationship between the three basic BIONAV subsystems (Satnav, Loran-C, and log/gyro) is illustrated by figure 2 and table 1. A more detailed analysis of the strengths and weaknesses of these systems is given by Grant (1977) and Eaton et al. (1976), while a description of the mathematical models used to combine them is given by Wells (1976). Integration improves navigational accuracy and reliability by using the strengths

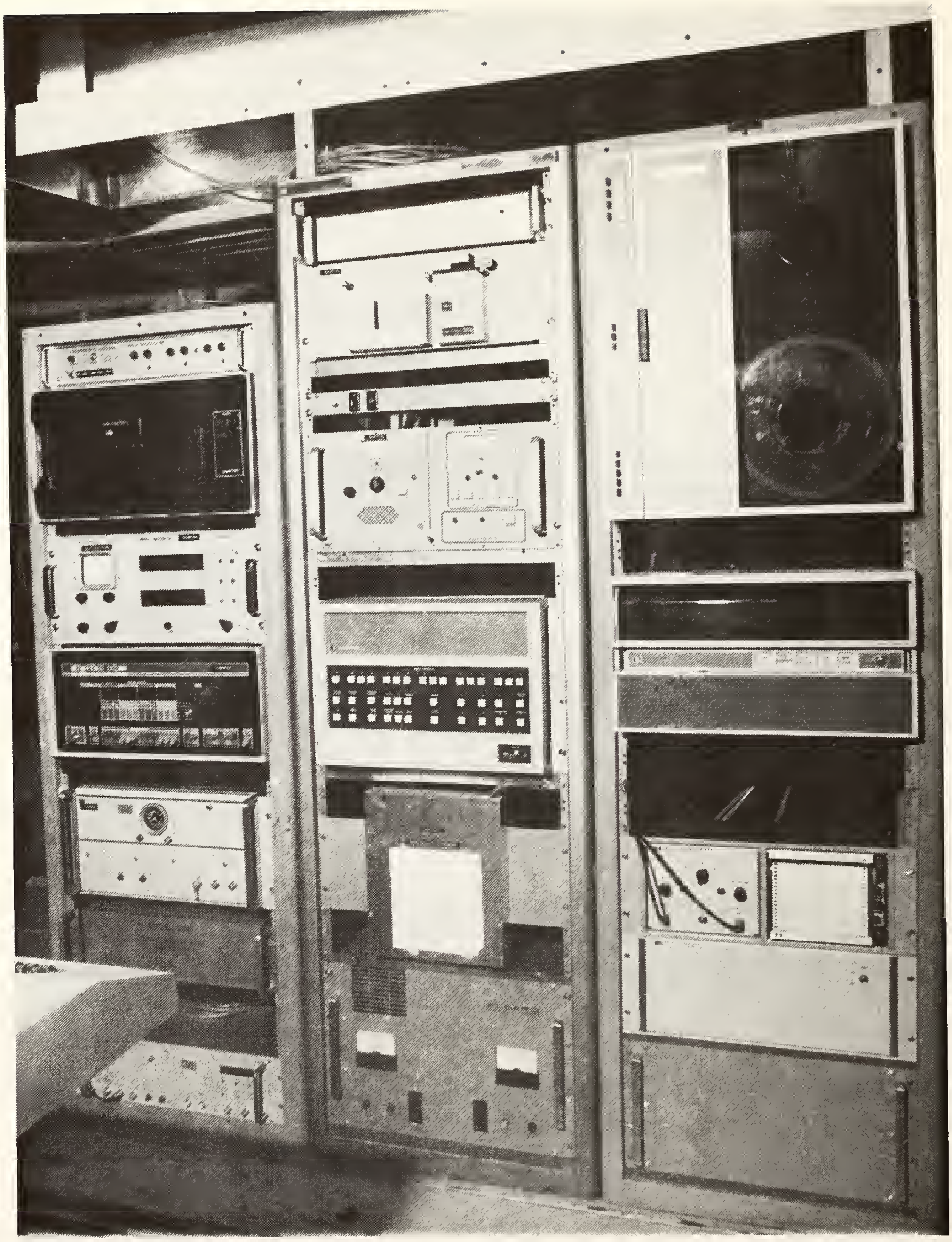

Figure 1.--The basic BIONAV system occupies the two right-hand racks, while the Austron Loran-C system is in the left-hand rack. The log, gyro, two terminals, and video displays are not shown.

of one system to compensate for weaknesses in the other system. In table 1, for example, we see that the long-term drift in Loran-C ranges (a weakness) can be compensated for by using Satnav fixes which have no such bias (a strength). Also, the intermittent nature of the Satnav positions (a weakness) can be compensated for by the continuous nature of log/gyro dead reckoning (a strength).

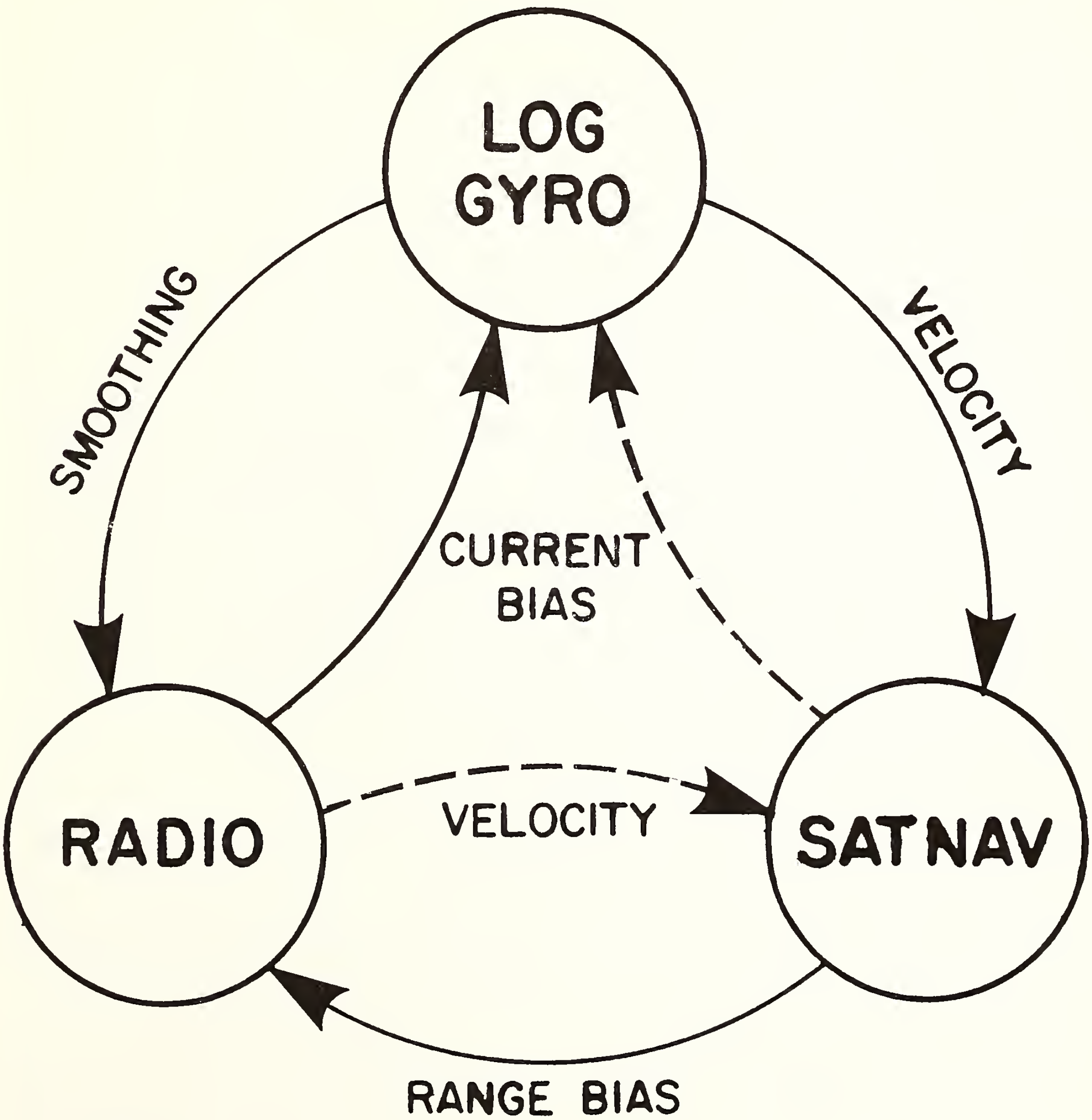

Figure 2.--The basic BIONAV system combines Transit Satellite Navigation (Satnav), rho-rho Loran-C, and ship's log and gyro by using the strengths of one system to compensate for weaknesses in the other systems.

Table 1.--Strengths and weaknesses of BIONAV subsystems

	Strengths	Weaknesses
Satnav	No long-term bias Worldwide coverage Absolute positions	Intermittent fixes Velocity needed
Loran-C	Continuous Medium-term accuracy Absolute positions	Long-term drifts Limited coverage Short-term noise
Log Gyro	Continuous Worldwide coverage No short-term noise	Medium-term drifts

In figure 2 individual Satnav positions, accurate to about 100 meters (m), are obtained a few times an hour and are used to update estimates of the Loran-C range biases (due mainly to errors in synchronization between the transmitter and receiver atomic clocks). Loran positions are continuously available between Satnav fixes, but, due to radio noise, Loran velocity estimates must be averaged over several minutes. By comparing Loran and log/gyro velocities, estimates of biases in the log/gyro velocities (due to wind and water current) are obtained. Corrected log/gyro velocities are used to describe the ship's motion during the 15-minute satellite passes. Secondary links between the three systems can also be used.

BIONAV OPERATION

One of the most difficult problems of the BIONAV development was designing the communications between the operator and the BIONAV system. It was mainly a problem of ensuring that the operator had adequate control of the system while at the same time keeping the dialogue clear and simple. We have had to make more changes in this area than any other following BIONAV's first field season. Figure 3 shows a sample dialogue between one of the main BIONAV programs (START) and the operator.

We have identified four classes of BIONAV operators:

Class 1 operators need know only how to turn BIONAV on and off and how to recover from system crashes (rare, if not extinct, events, we hope). They trust the defaults built into BIONAV and do not want any output except the minimum terminal listing.

Class 2 operators need to know how to exercise all the program options built into BIONAV. They should understand the program structures and

interactions thoroughly and be able to obtain the output in a variety of ways. They must be thoroughly familiar with RTE.

```
*RU,START
 START COMMAND =AL (NEW COMMAND OR SP/CR) ? HE
       REPLIES ARE AL,EX,HE,LA,PO,CO,SP,HT,TI,PR,LO,CP,
       WHERE
 AL =  DO ALL COMMANDS
 EX =  EXIT FROM START PROGRAM
 HE =  HELP (LIST REPLIES)
 LA =  CRUISE LABEL
 PO =  POSITION
 CO =  COURSE
 SP =  SPEED
 HT =  ANTENNA HEIGHT
 TI =  TIME UPDATE
 PR =  PRIORITY STRING
 LO =  LORAN SYNC UPDATE BY SATNAV
 CP =  CPU/CPU TRANSFER
 START COMMAND =AL (NEW COMMAND OR SP/CR) ? AL
       LABEL        =  80-001       NEW LABEL       (10 CHAR) ?
       LATITUDE     =  44 40.199 N  NEW NORTH LAT   (DEG,MIN) ?
       LONGITUDE    =  63 36.000 W  NEW EAST  LON   (DEG,MIN) ?
       COURSE       =         .0    NEW COURSE      (DEG    ) ?
       SPEED        =         .0    NEW SPEED       (KNOTS  ) ?
       ANT HT       =       20.0    NEW HEIGHT      (METRES ) ?
       TIME TAG     =     2.14. 3.20     REPLY 'YES' TO UPDATE?
       OLD PRIORITIES = MA,GB,LO,GC,GP,SA,DE,MI,OM,    ,  ,
       NEW PRIORITIES ?
       NEW PRIORITIES = MA,GB,LO,GC,GP,SA,DE,MI,OM,    ,  ,
       REPLY 'YES' TO INHIBIT SATNAV UPDATE OF LORAN SYNC ?
       TRANSMIT 'NO' DATA TO MAIN CPU (NEW LABEL OR 'NO') ?
 START DONE!
```

Figure 3.--Sample dialogue between program START and the operator.

Class 3 operators need to know how to modify and augment BIONAV Fortran software.

Class 4 operators need to know how to generate a BIONAV system.

The BIONAV operator's manual, written in four volumes corresponding to these four classes of user, was written using the BIONAV system as a word processor and is a file on the BIONAV disk. Copies can be printed using the word processing capability of the BIONAV system.

The operational part of the BIONAV software consists of six programs called GYROL (gyro/log), LORAN, SATNV, WAYPT, START, and BIONV. The operator uses the first five. The first three acquire, process, list, and log the data into their respective subsystems. They also include routines to permit the operator to do such things as change the list rates, change the log or gyro input to/from auto or manual, add fixed corrections, help LORAN identify unknown signals, tell LORAN to ignore the latest Satnav update, etc. Program WAYPT enables the operator to enter or change up to 10 waypoint positions for line running or homing. Program START initializes the system and enables the operator to change the cruise label (logged with each of the data files), position, course, speed, antenna height, and also the integration method (e.g., using LORAN velocity instead of GYROL). Program BIONV uses the information from WAYPT and START plus the data from GYROL, LORAN, and SATNV to do the system integration, perform the waypoint calculations, and display the appropriate results on the video displays. BIONV also lists on the console and logs on disk files.

The raw and processed data from GYROL, LORAN, and BIONV are logged on disk files, each containing 1 hour's data, that are overwritten every 48 hours. The SATNV data are logged one pass per disk file; 100 passes can be stored before they are overwritten. Utility programs enable the operator to transfer all or part of the disk files to 9-track magnetic tape.

Little operator training is needed; in preparation for the 1979 field season we gave a 2-day BIONAV course at the class 2 level to about a dozen people at BIO. We will repeat the course this year to bring last year's operators up to date and to train new operators.

BIONAV PERFORMANCE

The first operational use of BIONAV was during a Loran-C calibration cruise in late 1978. Now four systems are in operation: three ship-based systems (one on the west coast, two on the east coast) and one shore-based development system. The response of the users so far has been very encouraging, and we will be hard pressed to meet the demands of the surveyors/scientists at BIO during 1980 with the two operational systems we now have.

The most unusual achievement of BIONAV so far was its use in a hut at the North Pole (average temperature -48^{o}) during March-April 1979 as part of the Lomonosov Ridge Experiment (LOREX). It was used mainly for real-time Satnav fix calculations at the main camp and for postprocessing

satellite data logged on cassette tapes at the two satellite camps. The objective of LOREX was to study the Lomonosov Ridge, which passes under the North Pole, from a moving ice camp (Weber 1979). BIONAV operated without fault for the 2 months.

So far there have been no failures necessitating the return to the original CMC Satnav configuration. There have been a few failures, in both BIONAV and the devices connected to BIONAV, but, because of its structure and the ease with which it can be switched to alternative sources of the same information, the impact of the failures has been minimized. For example, the ship's Doppler logs are particularly troublesome in ice, during rough weather, and on station because of the propeller wash. BIONAV offers two possible solutions to this problem; the operator can switch the log input from automatic to manual and enter his estimate of the ship's speed, or he can change the priority structure so that program BIONV takes the velocity information from LORAN. The second alternative is usually chosen. It is significant to note that this choice was not available on the original CMC Satnav configuration.

To check on the reliability and accuracy of BIONAV, navigation data collected on a typical 2-week period during a hydrographic cruise off the coast of Nova Scotia were analyzed. This period was chosen because BIONAV was not being used as the primary navigation system, the operator was a typical class 1 operator who had other responsibilities besides looking after BIONAV, and the Austron rho-rho Loran-C system was being run independently of BIONAV by one of BIO's most experienced operators, using the same techniques that have been in use for the past 6 years (Grant 1973). This provided a good check on the BIONAV accuracy.

Table 2.--Data lost from hardware and software failures over a 12-day (299 hours) cruise

Cause	Real-time data lost (percent)	Data recoverable with postprocessing (percent)	Data totally lost (percent)
Hardware/software system	1.1	0.4	0.7
BIONAV software	1.3	1.3	0
Totals	2.4	1.7	0.7
Total hours	6.9	4.9	2

The percentage of data lost due to hardware and/or software failures is shown in table 2. These figures represent the time from the occurrence of the fault until the operator (class 1) had the situation completely under control. The first column shows the loss of real-time navigation information; however, during most of this time raw data were still being logged on disk files. Estimates of the amount of data recoverable through

postprocessing are given in the second column,and the percentage of data lost completely by BIONAV is given in the last column. When BIONAV is the primary navigation system, the Austron Loran-C system is usually listing independently so Loran data are seldom totally lost.

The distances between 63 "good" Satnav fixes and the corresponding Austron Loran-C and BIONAV Loran-C positions (uncorrected by Satnav) were found. The mean and root mean square (rms) distances are shown in table 3. We believe that the difference in scatter between the BIONAV and Austron systems is probably not significant, although it may be because the BIONAV Loran-C synchronization corrections are updated after every Satnav fix, whereas the Austron synchronization corrections may not be updated for several hours.

Table 3.--Biases and scatter in the BIONAV Loran-C and Austron Loran-C positions from comparisons with 63 "good" Satnav fixes

	Bias (mean distance between Loran and Satnav fixes)	Scatter (rms distance between Loran and Satnav fixes)
BIONAV Loran-C	37 m	115 m
Austron Loran-C	9 m	132 m

The scatter indicated by table 3 is due to noise in both the Loran and Satnav fixes. We believe the Satnav fixes are slightly noisier and estimate that the Loran-C scatter (both BIONAV and Austron) is about 60 to 80 m while the Satnav fix scatter is about 100 to 120 m.

The 9-m bias in the Austron Loran-C positions is probably not significant; however, we believe the 37-m bias in the BIONAV Loran-C positions may be due to a slight error in the assumed land conductivity used by BIONAV. Every 15 minutes a program in BIONAV searches a digitized coastline of North America for intersections of the coastline with the radial between the ship and transmitter. A table of land and water segments is created and, using Millington's Method (Millington 1949) and assumed land and water conductivities, the total theoretical overland phaselag is computed and used for the next 15 minutes. Overwater phaselag is computed for every fix. We have made a minor adjustment to the land conductivity used by BIONAV, but this is not the final solution. Since land and water conductivities change from season to season and from area to area, we are now working on a method for updating them automatically in BIONAV. For comparison, the Austron operator periodically enters corrections for overland phaselag for each range into the Austron Loran-C system. He scales the correction from phaselag contour maps prepared by the same program used in BIONAV. He also keeps a graphical plot of the biases in the observed Loran-C ranges from comparisons with Satnav fixes. The biases should be the same for all ranges from the same Loran-C chain, but they are slightly different due mainly to errors in the overland phaselag corrections.

The operator enters additional corrections for each of the observed ranges into the Austron system based on these plots and, in effect, compensates for the different phaselags along each of the propagation paths.

During June and July 1979 BIONAV was used on a geophysical cruise to the Labrador Sea off the southwest coast of Greenland. The scientists wanted to study the crustal structure and subsurface geology by placing four ocean bottom seismometers (OBS) at preselected locations and setting off up to 600-pound charges at various distances from them. BIONAV was used to predict the times and distances to go to successive shot points about 1 minute apart for seismic lines almost 200 kilometers long. That this feature was available to the scientists within 30 minutes of the initial request demonstrates the flexibility of BIONAV. For BIONAV the cruise was very successful.

The cruise was somewhat less than successful geophysically because of the loss of three of the four OBS's. When the OBS's did not appear on the surface as expected, a search pattern was designed based on the surface currents estimated by BIONAV during the previous few days, and one OBS was found.

This was the first cruise where the link to the ship's general purpose computer was used operationally. Since there was a Calcomp drum plotter on the general purpose computer, we plotted the ship's track in real time for most of the cruise. Figures 4 and 5 are two examples of these plots. Figure 4 shows the turns at the ends of the seismic lines, while figure 5 shows the drift of the ship during a camera station.

FUTURE ADDITIONS TO BIONAV

The limited number of input/output slots, memory (32K), and processing speed of the HP 2100 have placed restrictions on BIONAV from the start. To overcome these limitations we are adding a microprocessor unit (MPU), built by the BIO Systems Engineering group, to accept input from the log and gyro as well as Decca, propeller RPM, and rudder angle. Not only do we gain input/output slots (by getting the log and gyro data from the MPU) and reduce the computational burden on the BIONAV computer, but we also improve BIONAV reliability because the MPU is capable of operating and recording data independently should BIONAV fail. The MPU will communicate with BIONAV via GPIB. We will be carrying out final tests of this unit early in 1980. To further ease the burden on the BIONAV computer we plan to switch to RTE-IV in early 1980, enabling us to increase the memory (initially) to 192K words.

During the geophysical cruise described in the last section the scientists found the real-time plots very useful, but the drum type plotter was inconvenient because the track was always either under the pen or rolled out of sight. We will therefore be interfacing a Tektronix 4663 XY plotter with a 17- by 23-inch plotting surface to BIONAV early in 1980.

Hyperbolic Loran-C receivers are presently being installed on BIO ships, and we expect to interface them to BIONAV within the next year or two. Some of the software changes and additions resulting from BIONAV's

first field season have already been mentioned. Two other features we plan to add in the near future are automatic Loran-C skywave correction (Livingstone 1980) and computation of the geoid height for use in the Satnav fix calculation.

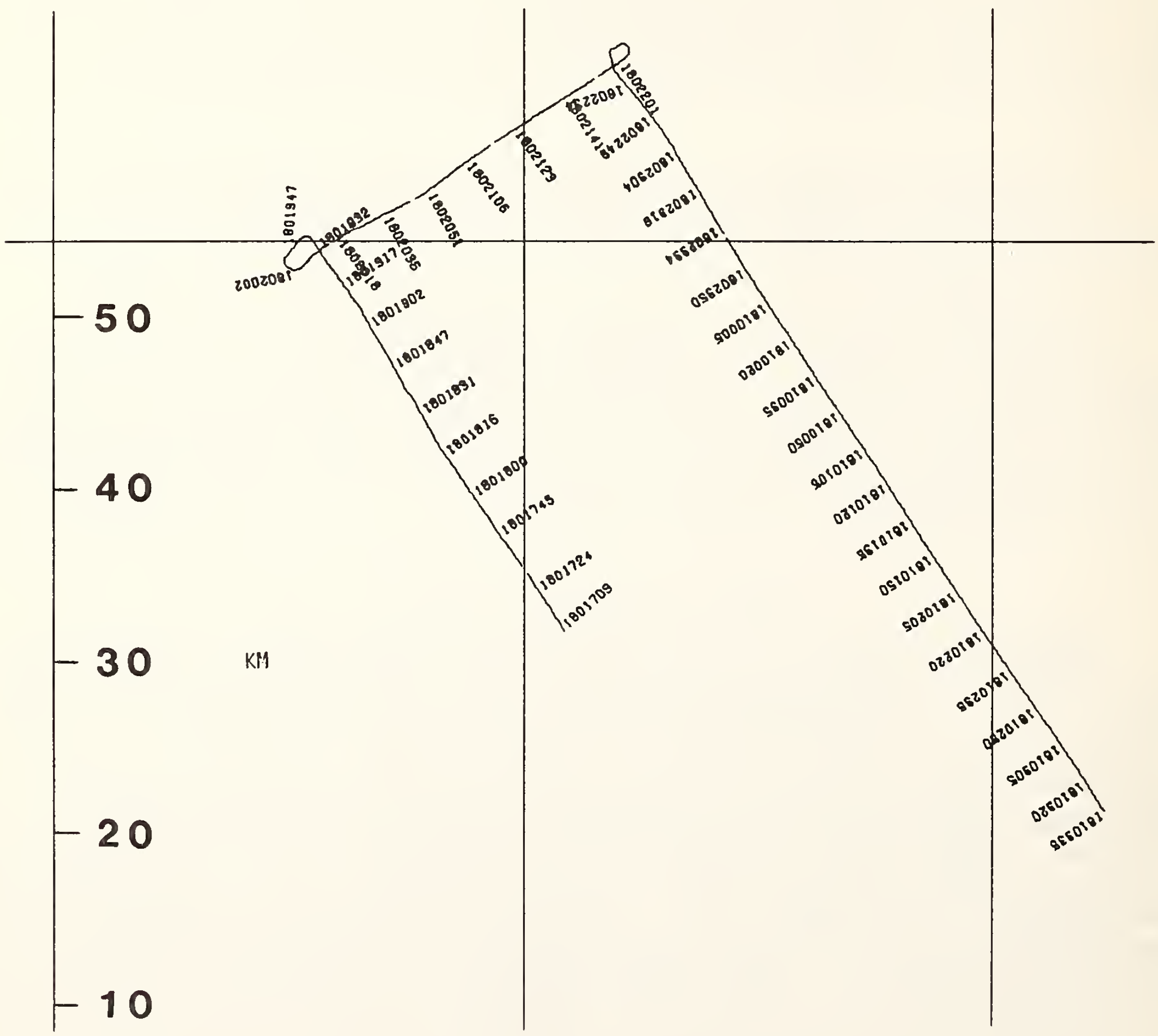

Figure 4.--Ship's track plotted in real time by the ship's general purpose computer using data obtained via a link to BIONAV. It shows the details of the turns at the ends of the seismic lines.

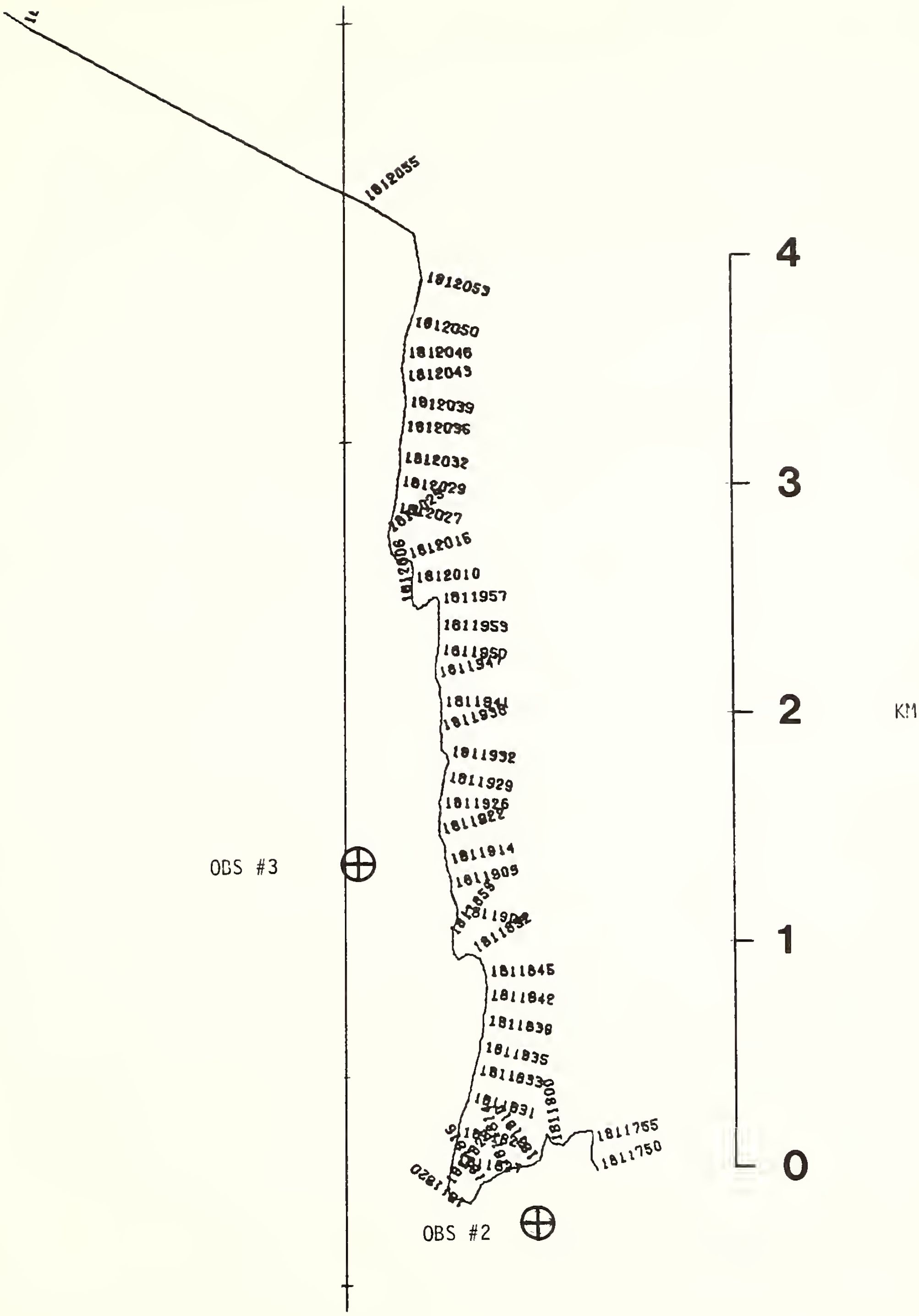

Figure 5.--A real-time plot of the ship's drift during a camera station.

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DISCUSSION

Lt. Cdr. Bass: I have two questions. First, what kind of graphic display do you plan to use on the future BIONAV's, and secondly, more importantly, what do you plan to put on them?

Mr. Grant: The past graphic display used the alphanumeric data--the time, latitude, longitude, and course speed; we have the estimates of the accuracies of those figures as well. Although we had line-running capability, it was a very basic numerical line-running. We have considered putting on the straight line as was shown in the NAVBOX.

Another feature that we had at that time was the plot of the ship's track and a latitude/longitude grid. We even took the coastline data that we had stored on disk as part of the phaselag calculation and flashed that up on a display as well, so you could see the ship's track and the coastline. That's all we've done, so far. And the other question was?

Lt. Cdr. Bass: Most of that is alphanumerical, I'm just wondering what kind of graphics you have of the coastline?

Mr. Grant: The only graphics that we foresee right now are the ship's tracks, perhaps--graphical line-running information.

Lt. Cdr. Bass: And what type of tube are you using?

Mr. Grant: At the present time, we're using simple, 9-inch Panasonic video displays, nothing fancy. That was why the last experiment with video was probably not too successful, because the grid was 256 by 256 and didn't have much resolution.

We do have Tektronix terminals on our ships, so I can foresee a test in the future of perhaps hooking one of those up to BIONAV to see what sort of results we get. Yes?

Lt. Mason: The system has a disk attached to it. What size ships are you operating on and are you having any problems with disk crashes due to sea action?

Mr. Grant: These are mostly on ships 150 feet and longer. The BIONAV system is mainly an offshore survey system. We've been operating the HP 7900 disks on our ships now for about the last 5 or 6 years, and I think we've only had two or three crashes in the whole time. We've been through some pretty rough weather with them, and they just seem to keep chunking away.

We have the removable cartridge and the fixed platter; the BIONAV system itself resides in the fixed platter. We use the removable cartridge for temporary storage of the data files. We can store 2 days' worth of data on rotating files that get overwritten every 2 days. We have utility routines for the operator to transfer data from those temporary files onto magnetic tape files.

Lt. Mason: In the same vein, if I may ask Mr. Macdonald, you mentioned problems recording with cassette tapes. Have you located the source of those errors or problems?

Mr. Macdonald: The problem we had with the cartridge recorders was either a software or a hardware problem with the piece of equipment that we had developed for us.

Lt. Mason: It wasn't necessarily an environmental problem, then, with regard to magnetic tape?

Mr. Macdonald: It could have been environmental, since we were using it in small boats and every time we put it on the bench it seemed to work fine. Yes, it is a problem using that type of recording media with small boats. But we hope to develop some solid-state recording media which should solve that problem.

Lt. Mason: Thank you.

Mr. Faulkenberry: What is the order of magnitude of accuracy of the velocity vector that you derived from the Loran-C?

Mr. Grant: It depended a lot on the weather. We only have a single component Doppler log. If there was a lot of wind, we found that the ocean current vector was almost useless. Fortunately, while we were running those OBS lines--seismic lines--there wasn't much wind. Those readings turned out to agree fairly accurately with what the chart had.

Mr. Faulkenberry: No, my question was, what was the order of magnitude of accuracy of the velocity vector that you derived from Loran-C and then mixed with Speedlog Gyro input? Did you assume the Loran-C was accurate?

Mr. Grant: We took the Loran-C velocity as being absolutely accurate, but with lots of noise. We damped it--filtered it with a filter constant of 3 to 5 minutes. Averaged over the 5-minute period or so, it was probably accurate to, I would guess, a few tenths of a knot--the Loran-C absolute velocity over the ground. We compared that with the log/gyro velocity. Because of the current bias in the log/gyro, we were able to estimate an ocean current vector. To answer your question, I think it's probably a few tenths of a knot.

Mr. Faulkenberry: Thank you.

INERTIAL SURVEY SYSTEM (ISS)

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ABSTRACT. In April 1979, the National Geodetic Survey used an inertial survey system (ISS) to establish second-order horizontal control along the Louisiana Gulf Coast in support of hydrography. The ISS, successfully installed in a NOAA Bell 204 helicopter, established or checked the position of 106 stations along the coast in 6 days.

This paper will discuss inertial technology, operational scenarios, various operational limitations, and how the inertial system was and could be utilized to support hydrographic operations.

INTRODUCTION

Development of inertial platform technology is relatively new. Its beginning can probably be traced to research done by Charles Draper of the Massachusetts Institute of Technology (MIT) as early as 1938, although the first real application can be traced to the German V-2 Rocket Program. After World War II, both the Instrumentation Laboratory of MIT under the direction of Charles Draper and the Redstone Arsenal under the direction of Dr. W. VonBraun began intensive development work on more precise inertial navigation platforms. Unquestionably, high-precision systems have evolved from this early exploratory research. Inertial systems are indispensable to missile guidance, have safely taken explorers to the Moon, and are used daily throughout the world for safe navigation of commercial aircraft.

DEFINITION OF TERMS

In order to understand the mechanics of an inertial survey system (ISS) a few basic definitions will be presented first.

Inertia--Inertia is the tendency of a body (mass) to resist acceleration. Inertia is the tendency of a body at rest to remain at rest, or a body in motion at a constant velocity to remain at that velocity and travel in a straight line. Therefore, anytime a body at rest begins to move or a body in motion deviates either in speed or direction from that motion an acceleration has occurred.

Inertial Reference Frame--An inertial reference frame is any frame of reference to which the Newtonian law of motion, "force equals mass times acceleration," is valid.

Gyroscope--A gyroscope is a rapidly spinning body (mass) having one to three axes of angular freedom. The spin axis itself provides one degree of freedom for the spinning mass. The remaining degrees of freedom are provided by the axes of the supporting gimbals. A gyroscope of three degrees of freedom allows the spin axis to be oriented in any direction. The spin axis in a three degree of freedom gyroscope will maintain a particular orientation even though the entire gimbaled system is put into motion. The gyroscope spin axis thereby acts according to inertia and can be used to provide a fixed reference system relative to some beginning known orientation. Gyro compasses are special purpose gyroscopes in that their spin axis becomes aligned with the rotational axis of the Earth. The Earth-related orientation produced by a gyrocompass is dependent on the phenomena of precession, gravity, and Earth rotation in conjunction with gyroscopic motion.

To mechanize a stable reference frame, gyroscopes of one-three degrees of freedom, gyroscopes of two-two degrees of freedom, or gyroscopes of three-one degrees of freedom are necessary. Single gyroscope systems tend to be the least stable and are subject to more random drift errors. Three-one degree of freedom gyroscopes are most stable but hardest to mechanize because of production tolerances and space limitations. Two-two degree of freedom gyroscope systems are a happy medium, although one axis will be redundant. This feature is not entirely desirable due to the correlations which develop between certain corrections during processing.

The reference system generated may be space oriented or Earth related. The space-oriented reference frame is one in which the initial orientation of the ISS is not important so long as its relation to an Earth coordinate system is determinable at the beginning of survey operations. An Earth-related reference system can be obtained directly by using gyrocompasses in lieu of gyroscopes. In this latter system the reference frame will be automatically oriented north and normal to the geoid (vertical). The duplicated coordinate axis is normally the vertical axis, because its orientation is most sensitive to motion and position on the Earth's surface.

Accelerometer--An accelerometer is an electro-mechanical device for measuring accelerations acting upon the inertial platform. A single degree of freedom accelerometer is normally composed of a tube with a highly machined steel ball inside which can move with little or no rolling friction. The ball is mechanically restrained in the center of the tube by being sandwiched between two steel springs. The compression of one spring and simultaneous expansion of the other can be used to measure acceleration. That is, if the ball is governed by inertia, it would normally remain at rest within the tube unless acted upon by some external acceleration. Since springs have a very small compression range in which they deform in a linear manner the ball is also kept in the center of the run with the aid of an electromagnetic force as well as the spring tension. The amount of current supplied to the electromagnet necessary to keep the ball from moving is a function of the accelera-

tion. If one knows the acceleration of a body then the double integration of acceleration with respect to a given amount of time yields the distance a body travels in that amount of time.

Inertial Platform--An inertial platform is a unique sensor used for position and velocity determinations of a moving vehicle from measurements of the vehicle's accelerations. The basic components of the platform are its accelerometers for measuring the total acceleration, the gyroscopes for mechanizing a coordinate system, and an on-time digital computer for real-time processing and control of the system. Some platforms are two-dimensional devices, such as the shipboard systems where elevation is known, and some are three-dimensional sensors analogous to missiles and geodetic use.

Physically speaking, the inertial platform is a flat plate oriented into a coordinate system by a pair of gyroscopes with three-single degree of freedom accelerometers aligned along the coordinate system's axes. The ISS designed by Litton Industries orients the plate carrying the accelerometers into an Earth-related coordinate system; i.e., latitude, longitude, and elevation, by using two-two degree of freedom gyrocompasses having a redundant vertical axis and one axis each orientated north and east. The plate carries the accelerometers such that there is one accelerometer oriented north, east, and vertical. The accelerometers, therefore, sense all accelerations in their north, east, and vertical components. The integration period is 16 milliseconds; therefore, every 16 milliseconds a change in latitude, longitude, and elevation is measured. If we know where the system was located at a given point in time, we can transport it to some new location, and by summing all the increments of latitude, longitude, and elevation and assuming no error during transit, we will know the location of the new point.

SYSTEM ACCURACY

From a surveying accuracy viewpoint, inertial systems can be classified into three categories--low, moderate, and high precision. These categories and typical parameter measurement accuracies for the four items of interest to the surveyor are shown in table 1. Note that an inertial system not only yields position but also elevation, gravity, and deflection of the vertical (difference between the gravity normal and astronomic normal).

Achievement of these accuracies is a function of both inertial system precision (including both hardware and software capabilities) and survey mission scenario.

Results from the Louisiana Traverse Task Number 83621178 are within the High Precision category of table 1.

ISS SURVEY SCENARIO

At the outset of the mission, the system is allowed 30 to 50 minutes to sense the local vertical, to orient itself automatically to astronomic north, and to perform an on-site calibration. Here the system's accelerometer signal,

the drift of the axes, and so on, are monitored to detect the degree of platform change from an actual static state. These estimates are then used in the software component of the system as a model to predict the performance of the platform during the survey.

As the vehicle begins to move, accelerations relative to the initial orientation are doubly integrated into geodetic position changes. This is done every 16-milliseconds and, almost instantly, the axes of the platform are rotated to conform with the corresponding spheroid orientation of the new site. This process is repeated continuously at 16-millisecond intervals until there is a need to update the platform errors. To achieve the update, the vehicle is brought to a complete stop for 30 seconds and allowed to seek the local vertical again. Because the navigation was performed on the spheroid, the angular change of the platform axes required to bring it to the local vertical represent the magnitude of the deflection from the vertical. Also, any residual velocity exhibited by the system in this "zero velocity" state is used to update platform errors. These "stop" operations continue until the system reaches the first station of the traverse and, eventually, the last. The gravity measurement is obtained from the system by recording the vertical accelerometer output at each stop, after the system has reoriented itself to the local vertical. With the systems currently available, the velocity updating process is repeated every 3 to 5 minutes. Since the system obtains its starting coordinates from some known point and computes its accumulated errors by completing a traverse on another known point, all those points established between the known points are actually obtained by the process of interpolation.

Traverses should be run twice, with one running in each direction of the traverse. Closed loop traverses are not acceptable,because the solution of system errors is not determinable from only one known control point.

Table 1.--Inertial Survey System accuracy

Inertial survey system precision class	Position control (1σ) Horizontal (Meters)	Position control (1σ) Vertical (Meters)	Gravity measurement error (1σ) Anomaly (Milli-gals)	Gravity measurement error (1σ) Vertical deflection (Arc-seconds, north & east)
Low	>3	>3	>5	>5
Moderate	1 to 3	1 to 3	2 to 5	>1.5 to 5
High	<0.5	<0.5	<2	<1.5

SURVEY APPLICATIONS

Inertial survey systems are very useful for establishing second- and third-order horizontal control. The system is capable of establishing control at speeds which are only limited to that of the transporting vehicle. On-line processing of data assists the pilot in navigating between control points, thereby maximizing survey time by minimizing transit time. Some unique survey applications of the system will now be discussed.

1. Recover and check control--The unique ability of the inertial system to navigate to a point whose coordinates are known permits economical recovery and checking of existing control. Search time at the site should be kept to a minimum and is economically controlled by the cost of return for further search without the inertial system and the probability of a successful recovery balanced against the need for the control. This is usually the first phase in a large project and normally takes 5 to 10 minutes per point ($40-$80).

In the Louisiana Coastal Traverse, three stations were considered "Most Likely Destroyed" during the last 20 years but were found within 5 minutes of landing at the station sites. Six other stations were positively confirmed as destroyed using the system (one station would be directly under the foundation of a house, four lie out in the Gulf of Mexico, and one in the middle of a man-made channel).

2. Densification--Horizontal control can be established as a portion of the project or as an end in itself. The use of established geodetic control or Doppler satellites for the basic control from which the ISS established secondary control has been extremely successful. In Louisiana, eight previously established stations were used to control the inertial system, which in turn established or checked the position of 72 other control points.

In a future project, being planned for the St. Marys River, seven horizontal control points would be established by Doppler Translocation (Short Arc Method) which, in turn, will be used by the ISS to establish approximately 120 new control points (including most fixed aids to navigation).

Another future project would utilize an inertial system within a framework of first-order geodetic control. The ISS would traverse both N-S and E-W through all new control points. This new procedure will hopefully improve the survey precision to better than 1:50,000.

3. Aerial photo control has been a major use of the system. The sparse spacing of the points and the requirement that they lay within the overlap exploit several advantages of the inertial system. Provided the project size is adequate, no other survey system can compete economically in this field. Maximum savings are dependent upon early planning, but costs have averaged one-half to two-thirds of conventional surveying. In featureless terrain, panels should be set and positioned at the same time using the ISS prior to taking the photos, whereas on many projects with identifiable features, photos may be flown when conditions are ideal and establishment of coordinates on photo-identifiable points accomplished later.

During the first 15 months of ISS operation in Canada, 1,908 second-order stations were positioned for mapping control.

4. The NOS could most effectively use an ISS for establishing hydrographic control. The ISS can establish Third-Order, Class I control to a density of one station per 3 kilometers (km). The control is independent of line of sight or strength of figure. This means the control is put exactly where it is needed without any need for further breakdown. With the proper planning, the locations of all electronic navigation sites, fixed aids to navigation, landmarks for charts, and calibration points may be established in one survey. The system can establish the control in a very short period of time (approximately 20 stations/day). The system is capable of working in any weather conditions and is limited only by the operational limits of the transporting vehicle. Any conventional four-wheel drive, half-ton truck, 1,000-pound payload helicopter, or any of various all-terrain vehicles may transport the system so long as the vehicle is capable of coming to a stable zero velocity stop. The system can be easily air freighted to remote locations and then installed in a vehicle near the survey area. One ISS could support all NOS requirements for hydrographic and coastal mapping control.

LOUISIANA COAST INERTIAL SURVEY

The Coastal Louisiana Traverse performed at the request of the Office of Marine Surveys and Maps (MS&M) to provide second-order control at 7- to 10-km spacing was accomplished a contract with Span International, Inc. NGS Field Party G-18 set all the station marks and performed the necessary ground work in February 1979. Transportation for the ground work and eventual survey was supported by the NOAA Bell 204 E helicopter. The ISS was chosen because the terrain was totally unacceptable for classical work involving Bilby Towers.

On April 1, 1979, the inertial system was ready to begin survey operations. Six days later the entire survey comprising 106 stations was completed. Subsequent analysis has shown that all stations are within Second-Order, Class II specifications with 50 percent of the stations exceeding 1:50,000 or Second-Order, Class I specifications. The average station spacing was 7.1 km with a total traverse distance of 453 km (one way). The entire survey was performed at a cost of $1,300 per station.

NGS may need to perform a second-order control survey along the St. Marys River at the request of MS&M. As currently reconnoitered, the proposed classical survey establishing approximately 30 new stations will fulfill MS&M's requirements for 7- to 10-km station spacing. If, however, a combination Doppler-ISS survey was performed with the average station spacing reduced to 1 to 3 km, all hydrographic control requirements could be met, including the location of all fixed aids to navigation and landmarks for charts. The control could be placed over sufficient numbers of photo-identifiable points to allow photogrammetric compilation of the shoreline detail. The Doppler Translocation of Short Arc Methods will establish sufficient control at a precision of 1:50,000 to control inertial surveys at precisions of both 1:20,000 and 1:10,000. Proposals are currently being sent to two companies. The inertial system would be carried in a hover craft from

point to point. This mode of transportation would be unique. The Canadian Government has expressed interest in the project and offered their expertise in planning and processing of the data.

The purchase of an inertial system has become more attractive to NOS due to the recent introduction of the Honeywell Geo-Spin System. The combination of such an inertial system and the NOAA Bell 204 E helicopter would give NOS the ability to support control surveys within NGS, NOS, and NOAA. The system would also be used to support the U.S. Coast Guard's need to locate fixed aids to navigation along the east coast. The initial investment is great--$500K to $850K for the equipment plus $50K per year for maintenance; however, this cost will be offset by a decrease in the cost per control point and in the number of costly delays often suffered by the hydrographic ships due to lack of control.

DISCUSSION

Mr. Westbrook: Who owned the equipment that you were testing?

Lt. Cdr. Lapine: This project wasn't a test; but actual production work. The helicopter was owned by NOAA and operated by NOAA research facilities in Miami. The system was owned by Span International; they are a leaser of inertial equipment. They provided the equipment, plus one technician. NGS supplied support personnel, planned the survey, and directed Span to the station sites to be surveyed. Span provided helpful hints on what we might be doing wrong and on how to improve the system accuracy.

Cdr. Richards: How do you locate something eccentric from the helicopter. For example, how would you locate a lighthouse?

Lt. Cdr. Lapine: We've tried several methods. The thing I didn't show you is the so-called hover site. It consists of a set of cross-hairs suspended on a pendulum and can be installed inside the helicopter. It operates like a periscope system; the pilot looks forward, his line of sight is deflected straight down, and he sees a swinging set of cross-hairs. He also sees whatever is physically below the helicopter at that point. He can hover over a fixed aid to navigation, watch for the cross-hairs to stabilize and center over the light, and then the pilot can punch a button. He has to do this three times. If all three positions of the inertial system are within 1 inch of one another, the system accepts those three values and means them.

The procedure I would use, because lights are sometimes moved on fixed aid structures, is to put a mark on the concrete pad of the structure, land if possible over the mark, position the mark, and then compute the eccentricities later for the light itself, or the plaque, or whatever is used to mark the site.

But you can hover over objects with relatively good results; I'd say 1 foot absolute position at best.

ARGO POSITIONING SYSTEM--AN OPERATOR's VIEWPOINT

Lt. Pamela Chelgren
NOAA Ship PEIRCE

ABSTRACT. Field operating experience and recommendations, including calibration procedures of an Argo Positioning System used on Lake Huron, are discussed.

Most of the field operators using Cubic Corporation's Argo positioning system this last year have gained experience with problems of installing and operating the system that could save other operators much grief and expense. This presentation is an attempt to provide a lateral exchange of information and some recommendations for users of this new system. Argo is a medium-range, phase-comparison positioning system with twice the transmitting power of Raydist. Argo and its microprocessor are endowed with some subtle features. Some examples of uses and problems experienced by the PEIRCE are the following:

Argo was used on the Cashes Ledge Project (OPR-SA104-PE-79). The signals received from our shore stations were very strong and steady during the entire project, and the partial lane correctors drifted only 8 meters (m). After the initial Hydroplot/Argo interfacing problems were resolved, the only difficulty encountered was a random 40-m "flyer" seen on pattern 2. This random error was seen on Hydroplot Programs RK111 and RK561. On RK561 it was seen on only four of the six manual interrupts used. No answer was found for the error at the time, since this accuracy still met our requirements on this project.

On the Lake Huron Loran C Project (OPR-SX914-PE-79) only one Argo failure occurred--the Antennae Loading Unit (ALU), at Port Sanilac. Other problems experienced included the following:

(1) Lane jumps occurred with skywave interference near dawn and dusk and with thunderstorm activities.

(2) Significant signal attenuation was noticed when we operated more than 50 miles from the stations.

(3) Differences of up to half a lane were seen with changes in land paths taken by the signal to the fresh water.

(4) The Argo software generated artificial rates and changes to rates when a station went off the air or when the Argo system was put into "standby."

Although three of these four problems are general characteristics that are associated with any phase-comparison system, often these characteristics, coupled with the Argo software, do not show themselves as simply and obviously as with Raydist. For example, we experienced some lane jumps during thunderstorms and in skywave periods that did show as a classic pattern on the saw-tooth record. We also experienced some lane jumps that appeared totally all

right and did not show the classic pattern. When the smoothing function in the system is working, it overrides the received signal to supply its computed rate as the output. This smoothing function is designed to produce rates that simulate undisturbed signals, and therefore, the actual disturbance can go undetected unless the operator observes the lights at that time on the control display unit (CDU), observes the edit tick mark on our newly designed sawtooth recorders, or (if the field party is lucky enough to have a thermal printer onboard) sees the annotation on the thermal printer record. This is why the newly designed sawtooth recorders are essential for processing. Because of the ranges and meteorological conditions we operated under on the Great Lakes, much final project data were created by the Argo software, probably around 25 to 35 percent.

All of the project data were not gathered at the same level of smoothing. We ranged from 0 to 5 on a scale of 10. Zero smoothing was used for signal quality inspection. It cannot be used with the Hydroplot system for data acquisition, because of a software bug that can generate lane jumps on zero smoothing. Code 1 was used as a minimal smoothing level when the command did not feel safe with using any smoothing. Code 2 was used in making turns and other ship maneuvers. Code 5 was used on-line. My personal understanding of Argo is that it can be used and was designed to be used as a "hands-on" system to milk out the greatest amount of usable data for your working grounds' conditions. Because it was designed as a hands-on system, and because (as a natural result of Murphy's Law) things are bound to go wrong only at the most critical points in a survey's acquisition, I feel very strongly that commands (i.e., Captains) whose parties are to use this equipment be trained in the use, the capabilities, and the limitations of Argo. Let me give an example of a phenomenon that should have been understandable, even predictable, if one had the proper training. We were steaming along with a code 5 in the Argo during a thunderstorm. When it became necessary to turn the ship to follow the shipping channel, a code 2 smoothing was initiated 2 minutes before the turn. The turn was made, and lane jumps occurred. The smoothing does not work as well in a turn, because it does not predict the rates as accurately. The more severe the turn, the more one will see this. During some strong thunderstorm and skywave disturbances, all we had to do to lose lanes was change the smoothing code from 5 to 2. Obviously, code 2 was not strong enough to hold the rates during these disturbances. Also, if too high a smoothing code is used it will induce lane jumps. One 270° turn induced lane jumps of 15, 3, 2, and 2 lanes on our four rates when a code 5 was accidently left in.

The big concern right now with Argo data is determining with certainty where lane jumps occurred when they are discovered. Several features are available, and others, with sufficient field user interest, could be designed for this purpose. One feature is lane identification, which can be called up on the CDU anytime and counts from 0 to 5. During our project we did not tune our ship's and shore's antennas for lane identification. I have heard from other users that this contributed to detuning their antennas. In spite of this, it is an extremely useful feature for detecting lane jumps. Another useful tool is the newly designed sawtooth recorder. Our old Epsco stripchart recorders have been equipped with two more pens that tick for the appropriate rate (like a fix mark's) whenever the smoothing overrides real-time data. Any of these annotated areas are good places to suspect lane jumps if the close-

out calibration warrants that. These 5-pin recorders are now standard for our users. One instrument that the PEIRCE was fortunate to have onboard for the project was a thermal printer borrowed from the Atlantic Marine Center Electronic Engineering Department (AMC/EED) to trouble-shoot an Argo software problem. As a processor I found it very useful in that it recorded all four rates monitored when triggered either by the Hydroplot or a time interval punched in on the Argo. The thermal printer also recorded annotations for edited and lost signals and changes initiated on the CDU. I then had access to a hard copy of when all the smoothing codes were changed, when rates were re-initialized, and checks on when the Argo's internal clock was reset. Even though this printer is much more than function printout, I still recommend its use on at least all projects monitoring more than two stations simultaneously. I know this printer was one of the reasons that most of our 2 weeks of Lake Huron project data could be processed and correctors justified. Another instrument that would be really handy to have, if it weren't for an interfacing problem with Hydroplot, is the Hewlett-Packard four-station track plotter. This plotter incorporates two 5-pin sawtooths with a thermal printer. As an alternative, some people in the Office of Fleet Operations (OFO) have talked about making the edit and lost signal annotations, the lane identification value changes, and the smoothing code changes available to the Argo output-computer input cable, so that, with some additional software, Hydroplot could print these on Teletype Two's printout. This would satisfy the need for an Argo function printout now only available by using the thermal printer.

By now this probably sounds as if there was much trouble and unclean data with the Argo. I don't want to leave you with the wrong impression about Argo. We were operating as far as 100 miles away from our stations, and on fresh water the signal attenuation is twice that over saltwater. Most of the time, our signal strength meter read between 2 and 5 for one or both of the stations used when the recommended low reading is 10. This low strength operation was conducted only if the signal was steady, when close attention was paid to the steadiness of the signal strength meter (even though it is dampened by software). Using short antennas for ease of station change, we had 27-foot top hat and 35-foot Shakespeare whip antennas instead of 100-foot Raydist-type antennas. I have been told that only a 1.7-dB increase in signal strength would result from using the taller antennas, but that number itself doesn't mean anything to me. Would it have saved us in some of our ship's maneuvers? Would we have had fewer lane jumps with thunderstorm and skywave disturbances? If Argo is to be used on the Great Lakes in midlake, I feel that a real-time test of the difference between the antennas should be made to justify using the shorter ones in midlake. Although the signals were further attenuated by land paths in our project, this is to be avoided not only because of signal attenuation but also because of differing propagation velocities. Land velocities range from 298,800 kilometers per second (km/sec) to 299,400 km/sec, and on this project our computed fresh water propagation velocity was 299,595 km/sec. This resulted in distortions over land of up to half a lane (i.e., 45 meters) on the signals monitored. Of course, with salt water operations the distortions per mile over land would be worse because the propagation velocity is even higher. This is something to be wary of in areas of large tidal flats and changes in signal land paths because of the geography.

Our method of calibrating the Argo with Del Norte was mentioned by Jim Shea. We used Del Norte rates only when the units were already calibrated with T-2 intersections and only if the check range gave an inverse of less than 8 meters. Given this setup, we only had to recalibrate the Del Norte once a week. I feel, with more rigid specifications for minimum inverse distances, that this method could be used satisfactorily for regular hydrography.

The actual equation I used for the velocity propagation calculation was:

$$V_{prop} = \frac{\Delta \text{ inverse} \cdot \text{frequency}}{\frac{1}{2}\,(\Delta \text{ lanes})}$$

A subtle feature Argo operators should be cognizant of is if a long signal loss is experienced or if the Argo is put into standby (i.e., when the ship anchors), the microprocessor, at normal smoothing levels, will go into a search mode causing the rates to speed up. The values will be way off when the system is reactivated. Since one of the functions of the microprocessor is to update without data, it will speed up in the search mode when it receives no data. The way to detect that a signal has been off the air--usually after one-half hour--is that the sawtooth (as well as the rest of the outputs) will display a very rapidly changing signal value. This differs from the straight line seen with Raydist.

To sum up my recommendations: (1) the users' commands should look upon Argo as a hands-on system and, in preparation for that, they themselves should get training on its use, capabilities, and limitations; (2) field parties should try to acquire as many Argo function printouts as possible in data acquisition, including the 5-pin sawtooth and the thermal printer, and should tune their antennas for lane identification; (3) field parties should also speak to the Office of Fleet Operations about alternative methods for acquiring Argo functions; (4) the 27-, 35-, and 100-foot antennas should be tested against each other on the Great Lakes; and (5) in fresh water and saltwater operations, land path signals are to be avoided.

I am giving Launch 1255's presentation for Lt. David A. Waltz, as he was unable to be here. General problem areas experienced by Launch 1255 were:

(1) System Setup. To date, Launch 1255 has made three complete fixed installations using three different antenna types. The initial installation was made by using the existing ground plane and tower sections (40 feet) of a Raydist station. Other antennas used were the 35-foot Shakespeare whip and the 27-foot Cubic whip antenna. This user prefers the Shakespeare antenna for overall ease of installation and performance. While less portable than the Cubic antenna, there are far fewer pieces to lose or corrode. Launch 1255 did experience antenna detuning problems which were traced either to loose connections or a faulty ALU. In any case, all antenna connections must be wrench-tight. A field intensity meter is helpful for initial tuning of a new installation because the "peak" is sometimes difficult to detect on the Range Processing Unit (RPU) meter. As with other meter indications on the RPU, there is often a short time lag between changes to cap or coil and an indication on the meter. Finally, it is not necessary to locate the power supply and RPU remotely from the ALU. Both arrangements were tried and both worked equally well.

Launch 1255 experienced several problems which were miraculously solved when power supplies were changed. Since this system depends heavily on software to maintain timing and accomplish all other functions, even a momentary interruption of power may cause problems. Wet cell batteries normally prevent loss of signal when shifting from ship's power to shore power, for example. However, back-up batteries did not prevent a cold solder joint in a power supply from causing many otherwise unexplained problems.

(2) Hydroplot Interfacing. Launch 1255 did experience major interfacing problems, and most have now been solved by AMC/EED personnel. The few that remain are important enough to mention here.

A time lag exists between the indication of lane crossing on the CDU display and the strip chart recorder. The same time lag occurs with data digitized by the Hydroplot system; discrepancies are on the order of 0.05 to 0.10 lane. For purposes of calibration, it is assumed that the Hydroplot system samples the Argo data at the point of actual phase measurement. For this reason, it is recommended that all calibrations, buoy circlings, etc., be digitized by the Hydroplot system, rather than by manual observation of the CDU.

One further interface problem could result from the "Delta Range" feature of the CDU. When the Argo system is initially brought up, a random "Delta Range" value appears on the digital display. The problem arises with the possibility of entering partial lane correctors on the Argo CDU, as well as on the Hydroplot controller. Some operators suggest setting the "Delta Range" values to zero before calibration. Onboard 1255, the procedure is to allow the random values to remain throughout the period between calibrations, and entering any corrector on the Hydroplot controller. In any case, the "Delta Range" feature should be left alone between calibrations.

(3) System Instability. In the survey just completed with Argo, there was no problem with partial lane correctors varying more than 0.05 lane from morning to afternoon calibrations, as measured by conventional methods. Limited measurements in different parts of the survey area also produced good agreement in partial correctors.

A major problem, however, appears to be in evidence when lane jumps occur. Launch 1255 experienced lane jumps that were not detectable from the sawtooth record. At least they were not detectable with smoothing code 2, which is recommended by Cubic Corporation for this vessel. The sequence of events for the first lane jumps seen by Launch 1255 went as follows:

(a) Pattern 2 digital display goes blank; automatic gain control (AGC) drops to zero.

(b) Vessel maintains constant velocity, sawtooth keeps tracking normally, with only minor irregularities. Hydroplot system continues to digitize data and take soundings.

(c) After approximately 5 minutes, pattern 2 AGC rises to normal level, CDU display comes on. Sawtooth lane count agrees with digital display. Continue hydrography.

(d) Lane ID feature indicates five lanes jumped, on pattern 2.

(e) Afternoon calibration confirms five lanes lost--undetected on sawtooth.

This problem appears to be associated with the smoothing code and raises questions about the smoothing feature and how it is to be properly used. It can be argued that on-line smoothing of raw data is useful, but the strip chart recorder also must be able to detect lane jumps as they occur or the entire sawtooth record is useless. It may be that operating personnel have simply not yet learned to recognize lane jumps as they occur with this system.

It is strongly recommended that modifications be made to the Argo system to ensure that the strip chart record is unsmoothed or de-smoothed.

(4) Mobile Antenna Detuning Due to Salt Spray. Probably the most common operating problem encountered on Launch 1255 (after equipment/installation problems are solved) has been keeping salt water off the antenna. Salt water on the antenna base and ALU usually detunes the system enough to cause high voltage standing wave ratio (VSWR) alarm lights and blank lane count displays. Admittedly, running hydrography in weather conditions bad enough to throw heavy spray is not such a good idea, but it is sometimes necessary. The problem would be accentuated when Argo is used in the type one survey launches.

The solution to the problem apparently lies in shielding the antenna base and the ALU lightning arrestor from spray. Different shielding arrangements will be tried aboard Launch 1255 during the winter operating season, and anyone making an Argo installation in a small launch should design a spray shield into the antenna mount.

DISCUSSION

Lt.(j.g.) Connors: I want to present a few things that we found on the RUDE and HECK this season. We used Argo exclusively throughout the field season. It was found to be extremely stable in most types of weather and operating conditions. Loss of production caused by ARGO equipment failure was minor, and even though personnel were inexperienced in maintaining and repairing the system and its components, an adequate supply of spare parts enabled us to keep the system downtime to an acceptable level.

In several cases, operator inexperience also led to loss of production. Equipment failures occurred both at shore stations and aboard the ship, with seemingly no regard for location. The unit failing most frequently was the antenna loading unit. The factory and the Electronic Engineering Division at AMC are aware of the problem. It's a mechanical problem in the unit itself, and they are trying to correct that.

The Range Processing Unit and Control Display Unit--the RPU and the CDU, respectively--failed about an equal number of times. The failures here seemed to be consistent with the general quality of the Argo system; most of the failures of the RPU's and CDU's can be traced to malfunctioning electronic com-

ponents. Such failures should not occur after the equipment has been operated for more than a few hours.

The power source failed only twice and was the most reliable of the components. Contributing to the failure rate was inexperience in troubleshooting the equipment. It is believed that some of the units were swapped out when they were working properly due to inexperienced repair people working on the Argo equipment.

Considering everything, we feel that the Argo performed very well during the course of the season, and expect increased reliability with the system improvements and greater familiarity with the systems.

Because the RUDE and HECK work primarily as day boats, Argo was put on standby, and contrary to what Pam experienced, we were able to calibrate, come in from the end of the day, and put one unit on standby as the other ship came up alongside the dock. And when we got underway the next morning, the outboard ship would turn the Argo on, lock on to the ranging unit, proceed out, and then the other ship would do the same. And when we compared calibration the next day, it was typically within one or two hundredths of a lane--I mean it was right on.

In addition, most equipment failures seemed to occur when the unit was in the standby mode. They usually happened overnight, and we would notice it the next morning. Problem corrections were accomplished before we actually got underway and it saved quite a bit of time.

As has been mentioned before by Jim and Pamela, 37-foot fiberglass whip antennas were used exclusively on our boats, and they performed very well and simplified shore station construction considerably. However, the RUDE and HECK maximum range throughout the season was 60 nautical miles in salt water, so we would expect these antennas to perform quite well.

Another interesting thing happened when we were working in the Chesapeake Bay; we were able to track both the ranges, R1 and R2, by both vessels inland a distance of 2 miles in a small creek without losing any lanes whatsoever. And throughout the whole year, we only lost lanes twice. One time occurred in the Gulf, when at this point we were just becoming familiar with the units and we weren't sure of the smoothing code features. And one ship had a smoothing code of zero, the other ship had a smoothing code of two. We were about 40 miles offshore, and we were experiencing a severe electrical disturbance. The HECK with the smoothing code of zero lost about four or five lanes, whereas the RUDE with the smoothing code of two, never lost a lane and held out right through the whole thing.

Later in the year we experienced lane jumps during an "abandon ship" drill. We had our life preserver box located up near one of the antennas. Apparently, either because the people were up in the area and causing some disturbance with the antenna, or maybe someone threw a life jacket up and it hit the antenna, but the HECK lost a lane on every rate during this drill and we could trace it back on the thermal strip chart recorders and pinpoint the exact time when it happened. It correlated exactly with when we held the drills.

Argo provides the operator with a great deal of easily obtained information about the performance of the system. To utilize the system to its best advantage we recommend that the following information be recorded during each calibration: one is the AGC values for each rate. Argo allows you to monitor your shore station sites as far as power output by the use of an AGC value meter, and you should record the rates from all of your station sites, along with your calibration. Also, the ship's antenna tune should be recorded in the volume--the Delta range values for each rate, as has been mentioned before, should stay the same for every calibration that you are on, and should be recorded. The time slots that are used by each vessel, should be recorded, and be the same. And the smoothing code used should also be recorded.

If these values are not consistent with those previously observed, the operator should realize that there may be a problem. In addition, the AGC values for each rate should be monitored periodically throughout the normal working day, to make sure that your station is putting out what it was in the morning, and what-have-you. Any change in these rates indicates a system problem, or a shore station problem.

Follow the recommended criteria for Argo station site selection, that is, the station should be within 100 meters of the water's edge, or more than 2 kilometers from the water's edge. And I'm going to discuss a study that we just did in New York here in November. In addition, while circle calibrating around a large metallic structure, ensure that you are far enough away from the structure so that it does not affect the calibration itself. You can get too close to some of these towers, at least we could, because we're only 90 feet--and it would affect the calibration--there was a difference.

Beware of running the Argo antenna lead close to and parallel with antenna leads of any transmitting radio. This was a major problem for us down in the Gulf for about a week and a half. One of the ships had their transmitting radio cable running in parallel with the Argo antenna cable for about 15 feet up and down the mast. The ship would calibrate and would head out for the item, or whatever we were working on. We'd be talking over the radio and when we keyed the mike the system would act as if a power failure had just struck the system. And at first we didn't correlate it with the keying of the mike, because we might notice it 2 or 3 minutes after we'd gotten through talking. And then eventually it had everyone buffaloed. Everyone was trying to ground everything out. Once we rerouted the transmitting radio, the house radio cable and ran it perpendicular rather than parallel, it eliminated the problem. Something like that might save somebody 2 weeks of headache, like we had.

If possible, obtain and use a thermal strip chart recorder. Not only are they more reliable and easier to use than the old type recorders, they also indicate the possible problem areas. On the analog record, we had an edit pen--so, you have not only a visual indication by the CDU, but you have a visual indication and a hard copy on the strip chart.

There is an idiosyncrasy in the Argo system that can lead to unnecessary retuning of the antenna. This was one of the operator problems we had the most trouble with. A few of the people we had onboard were new,and they hadn't attended the Argo school. When they checked the antenna tune and put it into

antenna check, if the system had just been turned on that morning, it took a couple of minutes for the capacitor in that meter to form and build up to the needle indication. Some of the guys would put it in antenna check and see that it was reading zero right away, and not waiting that extra time for the capacitor buildup, would immediately go to the antenna tune mode and try to tune a perfectly tuned antenna.

One of the main advantages of Argo over previously used systems is the excellent stability, even during periods of extensive electrical activity. This is what we found, expecially in the Gulf. Before we had Argo, we were using Raydist. Down in the Gulf, off Galveston, we'd be out working 10 hours a day, come in with some tremendous amount of wire drag and 40 miles before we hit the calibration site in the evening we'd get knocked off the air with an electrical storm. Not only was this costly, in as far as ship's time was concerned, but it was very frustrating for people doing the actual hydro.

Other advantages are the ease in establishing shore stations using 37-foot whip antennas, which have been previously mentioned; the ability to monitor shore station performance from the ship, which is a nice feature; the ability to use three or four ranges simultaneously for increased reliability and accuracy; the lane identification feature, which tells you if you have lost lanes; remote antenna tuning; and the ability to use multiple, easily selectable frequencies. The Argo system has 16 different frequencies that can be used, by just switching on each of the units themselves.

To get the most out of the Argo system, the operators must be well trained. Perhaps this is probably the most important point. Argo is a complex system, much more sophisticated than Raydist, and offers much more information than can be obtained from Raydist. However, utilizing all of Argo's capabilities requires much more human interaction from the operator than does Raydist. It is extremely important that the Argo user be well schooled in the concepts and techniques necessary to use the system to its fullest advantage.

That's about all I have to say as far as our experience goes. I'll just briefly mention the velocity propagation study we did in New York. We were sent out at the end of November to do a couple of items in the apex of the New York Harbor area. We had an item here, one down here, a couple here, and a few in here, plus a few up farther in the Harbor area. We realized, of course, that if we had 1 month up there, we were not going to get all these items done, and if we got one done we would be lucky. But we are thinking ahead, in terms of next year and where we were going to set up station sites.

Two areas--R1 is Rockaway and R3 is Sandy Hook--had been these previously with Raydist, and we figured rather than resurvey we'd go up and use those right away. However, a geometry of let's say, item 3, by using R3 and R1, is just straight lines, you have no angle there, so you obviously couldn't use those two station sites for that item. So we established this extra site out here in Fire Island. We went up here using three stations. And as you can see, most of the items we had real good geometry--1 and 2, using R2 and R3 here, 3 and 4, using this one and this one, and inside we used R3 and R1, and got nice angles.

When we got up there, we had three places that we could survey and calibrate. We had Ambrose, Romer Shoals Light, and West Bank Light. After we had been up there a while, we realized that when we calibrated here and carried it over to here, we were getting considerable changes in our rates, as far as calibration was concerned. Even between these two, which are located only 2 miles apart, we were noticing unexplainable differences. So we did more or less a study of this area and if I can flip this over--I hope everyone can see this all right--this is Ambrose to Romer Shoals and the land path involved with the station of the signal from Ambrose to R1--from R1 station, which is the one located around Rockaway there, the land path was about a tenth of a nautical mile. From Romer Shoals to R1, station located at Rockaway, it was three-quarters of a nautical mile. The difference between the two is 0.65 nautical miles, and the difference in range as far as lane count was about two-tenths of a lane. Argo and the Hydro Manual (section 4.4.3.4) are in good agreement in that the station should be as close to the working ground and as close to the water as possible. And Argo goes on to say, and I quote, that the "fixed stations should be located less than 100 meters or more than 2 kilometers from the water's edge." The rationale for this statement is that land paths cause rapidly varying values of phase shift lags through the first 2 kilometers of travel. After that distance, the phase shifts increase at a relatively constant rate with distance. Also we have in here the fact that the water inside the apex was about 27 parts per thousand salinity and the water outside was about 35 parts per thousand salinity. So that might also have a slight reason for these changes. Of course, you have a different propagation velocity with different salinity--although that's not the biggest factor--the biggest factor here was the land path consideration.

As you look these figures over, you can see that in this area these values agree pretty much. Here we have a difference of 0.65 nautical miles and 0.52 nautical miles, and the difference in the values are pretty consistent. However, the critical value is 100 to 200 meters--to 2 kilometers, which is approximately 1 mile. That is, Argo is saying that between a tenth of a nautical mile and 1 nautical mile, you should note your greatest change as far as lane path. And you can see here this is true. Here we have the difference between Romer Shoals and R2 station was 2.2 nautical miles, and West Bank Light and R2 was 9.1 nautical miles lane path. Both of these areas are outside the 1 mile critical area, or a difference of 6.9 nautical miles as far as land path goes between those two calibration points.

The Delta range value is 0.21, which is, you know, very close to this right here. So what Cubic Western is saying, is even though this may seem great, it's not going to affect your change in range, as much as this difference in that shorter critical area.

I want to emphasize this wasn't a thorough study. We didn't generate that much data, and we weren't out there that long. However, it does indicate everything that Cubic Western does say about the system itself, and we're going to go back up this year and resurvey a few areas closer to the water so that we won't have as many problems with it next year.

If there are any questions that I can answer, I'll be glad to try.

Lt. Cdr. Floyd: I have a question concerning the smoothing function. I have a rough idea of what you're talking about, but I don't know how it works. Does it store some data and look at how fast you're crossing the rates, and then calculate some new values and compare that with what you're getting?

Lt. Chelgren: Yes, it's similar to that discussion about gating that you heard about earlier with the sounding equipment. It anticipates a certain lane value.

Lt. Cdr. Floyd: Okay, well that's my question. How does it anticipate this? It has to look back at the old records and see how fast you're crossing the lanes, doesn't it?

Lt. Chelgren: Right. It notices that, calculates the change per time, and expects a new value at the next interval. It has a certain gate depending on the smoothing level that it's been given. It gets a more rigid gate the higher the smoothing. If you're not within that gate, it's going to give the value that it wants--the one that's predicted.

Lt. Cdr. Floyd: Right, okay.

Lt. Chelgren: Is that correct, Jack? Okay.

EVALUATION OF DUAL BEAM WIDTH SOUNDING SYSTEMS IN HYDROGRAPHIC SURVEYING

PART I

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ABSTRACT. The narrow beam echo sounder has become commonplace in hydrographic surveying. This has reduced the bottom area insonified by the echo sounder's beam, which decreases the probability of detecting navigational hazards. The dual beam echo sounder, equipped with a narrow and wide beam sounding concurrently, represents a relatively inexpensive means to increase the detection capabilities, while preserving the narrow beam operation. System design, field operating procedure, and some of the advantages and disadvantages of a dual beam sounding system installed in a type 1 aluminum survey launch are discussed. The wide beams detected significant peaks that were absent on the narrow beam trace. The wider hyperbolic returns of the wide beams served to emphasize the narrow-beam returns over features with little horizontal extent. The narrow versus wide beam depth differences over feature peaks were found useful in isolating the peak's apex.

PART I

INTRODUCTION

As the hydrographer's echo sounder has evolved into a higher frequency and narrower beam sounding instrument, an increased problem with bottom coverage arises. The insonified bottom area is substantially reduced using the narrow beam echo sounder. In addition, the line spacing required to adequately detect and delineate shoaling features is decreased. The hydrographer's

objective of detecting hazards and the objective of high resolution accuracy using narrow beam sounders are contradictive when using a single-beam sounding system.

The problem of bottom coverage is well illustrated by a recent National Ocean Survey (NOS) hydrographic survey in Cook Inlet, Alaska. Figure 1 is a position plot of a survey launch's efforts to confirm reported shoals of about 6 fathoms in sounding depths of 10 to 15 fathoms, using a 7.5° beam width transducer. The investigation eventually led to a wire sweep. There is a natural tendency to initiate this type of investigation with the echo sounder. When the echo sounder has a narrow beam width, the investigation rapidly evolves into an attempt to cover fairly large areas with sounding line spacing of only a few meters. The result is a substantial investment of time by the field hydrographer, and a disproportionate increase in the time required to process and verify the data. Figure 1 was created from blow-ups originally requested by the survey verifier, who required them to manage the high density of soundings in the investigation area.

PROJECT DESIGN

This project was designed to assist in evaluating any possible benefits or problems encountered while using echo sounders with various beam width and frequency concurrently during hydrographic surveying. The design was oriented toward launch hydrography in shallow water (less than 100 fathoms) because a dual beam system, which is considered a relatively inexpensive and a partial solution, applies better to launch work. The installation and operation of a dual beam system is relatively simple.

In contrast, the multi-beam, swath systems require more space for the processors, peripherals, and mounting the transducer array. These higher technology systems that increase bottom coverage will be adopted first by ship hydrography. In fact, most of the prior studies with these more complex systems have been done in deep water, where the problems with spherical spreading of the wide beam are not as severe as in shallow water.

Therefore, our project was designed primarily to evaluate the dual beam system. Particularly, its abilities in two areas (fig. 2):

(1) Peak Detection - The dual system's wide beam increases bottom coverage and the probability of detecting shoals of small horizontal extent.

(2) Peak Isolation - The narrow versus wide beam depth difference is zero on the apex of a peak. The wide beam always records shoaler depths on a sloping bottom than the narrow beam. This characteristic of a dual system assists in locating the feature's apex.

To evaluate these factors, a limited area survey was undertaken at a reduced line spacing, relative to NOS standards, to delineate small-scale features. The launch was equipped to sound simultaneously with three beam

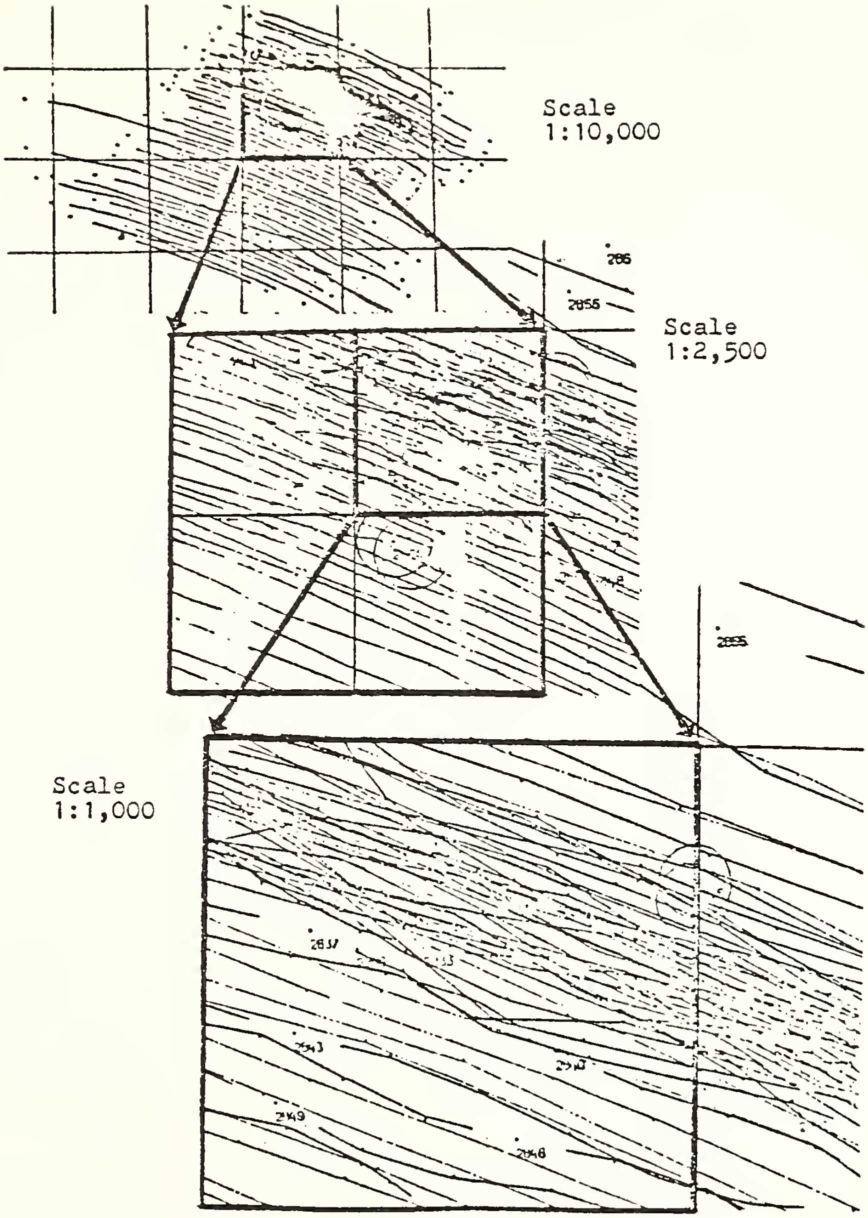
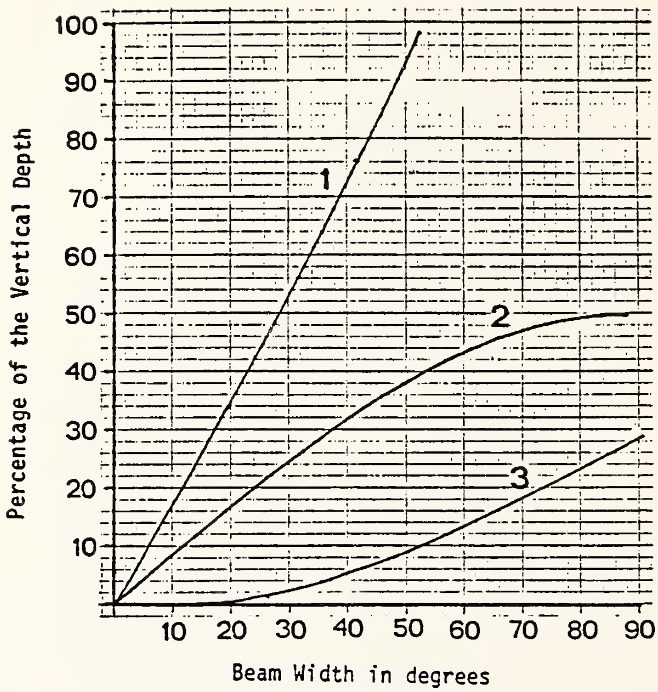


Figure 1.--Position plot of a search for a bottom feature.



θ = Beam Width/2

Curve#1 - $2 \times \tan(\theta)$
Diameter of the insonified bottom area

Curve#2 - $\cos(\theta)\ \sin(\theta)$
Maximum horizontal error in the position of a recorded depth

Curve#3 - $1 - \cos(\theta)$
Height of a feature that may be hidden in the echo smear by spher ical spreading at the lateral limits of the beam.

Figure 2.--Functions of beam width.

widths and two frequencies. The peak detection capabilities were measured by the small-scale features detected by the wide versus narrow beams. While peak isolation abilities were measured by the depth differences, wide versus narrow, as the sounding lines crossed adjacent to, or over feature peaks (figs. 3, 4, and 5).

EQUIPMENT

Generally, NOS hydrographic launches are equipped with automated surveying systems that include a 7.5° echo sounder. All beam widths are referred to the 6 decibel (dB) down, or half-power, level. In addition, a 28-foot launch from the NOAA Ship RAINIER was equipped with a 22° transducer to assist in locating reported shoals. Subsequently, the NOAA Ship RAINIER requested the 7.5° and 22° beam transducers be designed to allow concurrent sounding to evaluate the benefits during various hydrographic projects. The launch's regular 7.5° narrow beam system was equipped by the Pacific Marine Center's Electronics Division to display the 7.5° and 22° traces on the same recorder. The two transducers operate at the same frequency (100 kHz). The 22° beam width transducer triggering was delayed by about 6 ms or 2.5 fathoms of recorded depth. The delay for the 22° beam was generated at its transceiver. The design of the 7.5° and 22° system is illustrated in the block diagram of figure 6. The digitizer received only from the 7.5° beam. The launch processing system recorded only narrow beam depths. The outgoing "start" pulse from the recorder and the returning signals from the two transceivers were simply connected together at a junction box. The gain and mark intensity of the recorder controlled signals from both transceivers.

For the study, an additional wider beam and lower frequency system was requested and temporarily added to the launch. This 25° by 60° beam system operated independently. The transducer was mounted on a portable strut on the starboard side of the launch with the 60° beam athwart-ship and the 25° beam fore and aft. The operating frequencies of 21 kHz and 100 kHz differed enough to prevent any interference problems. This system added a second frequency and extended the beam width to a degree that was envisioned as closer to the useful limits in shallow water hydrography.

The sounding equipment is listed in table 1. The project was designed using the existing inventory of sounding equipment from NOS' Pacific Marine Center with the underlying desire that a useful and readily available permanent system might exist.

NARROW AND WIDE BEAM SOUNDING OVER INDIVIDUAL FEATURES

Large-Scale Features

Figure 7 displays the 45-m sounding line profiles over an 11-fathom peak from the northeast corner of area two. Each of the dual beam profiles has a difference, narrow versus wide, indicating shoaler depths. Sounding line 2692-2694 gave an indication of where to look for the apex of the peak. Line 6192-6194 is 3 fathoms shoaler. Unfortunately, line 6192-6194 happened to be run by a narrow-beam-only launch (fig. 8).

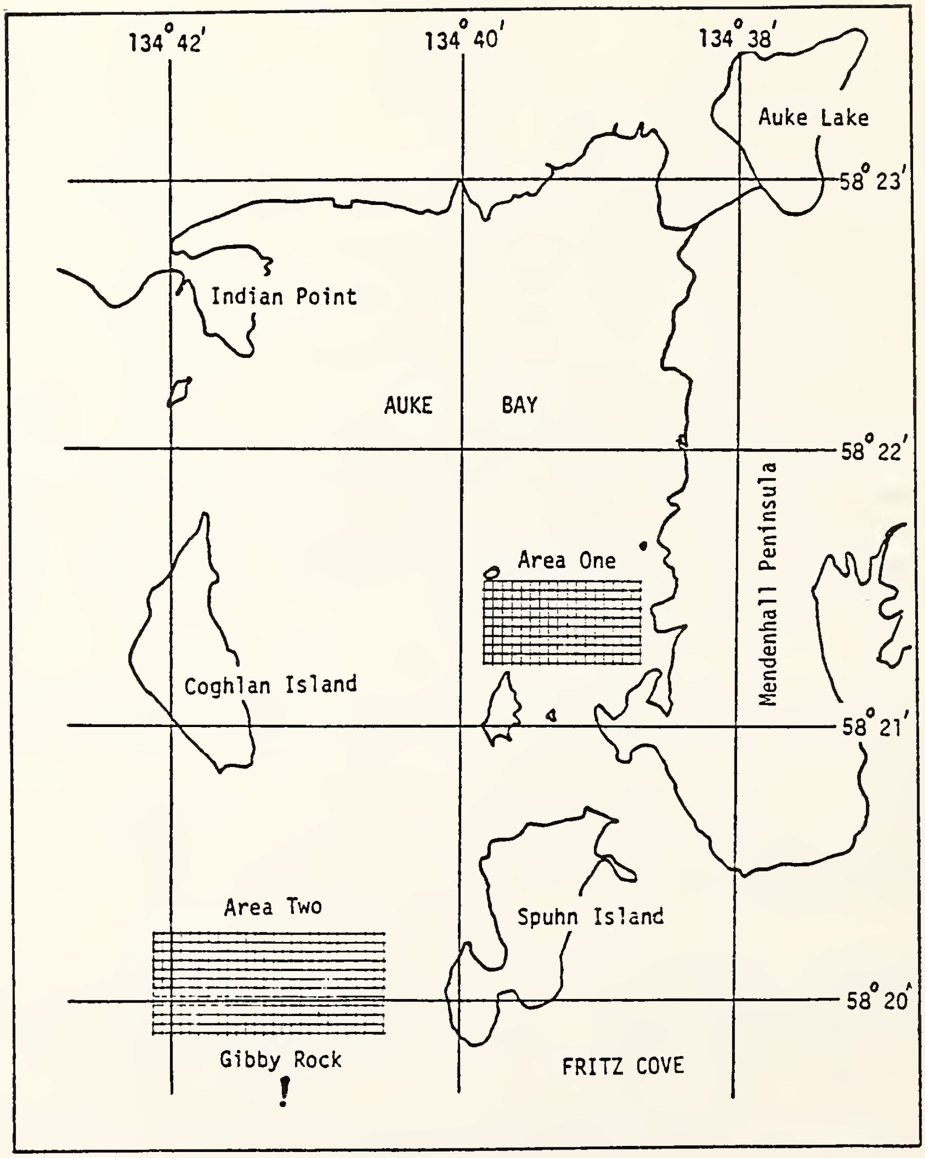


Figure 3.--Project area.

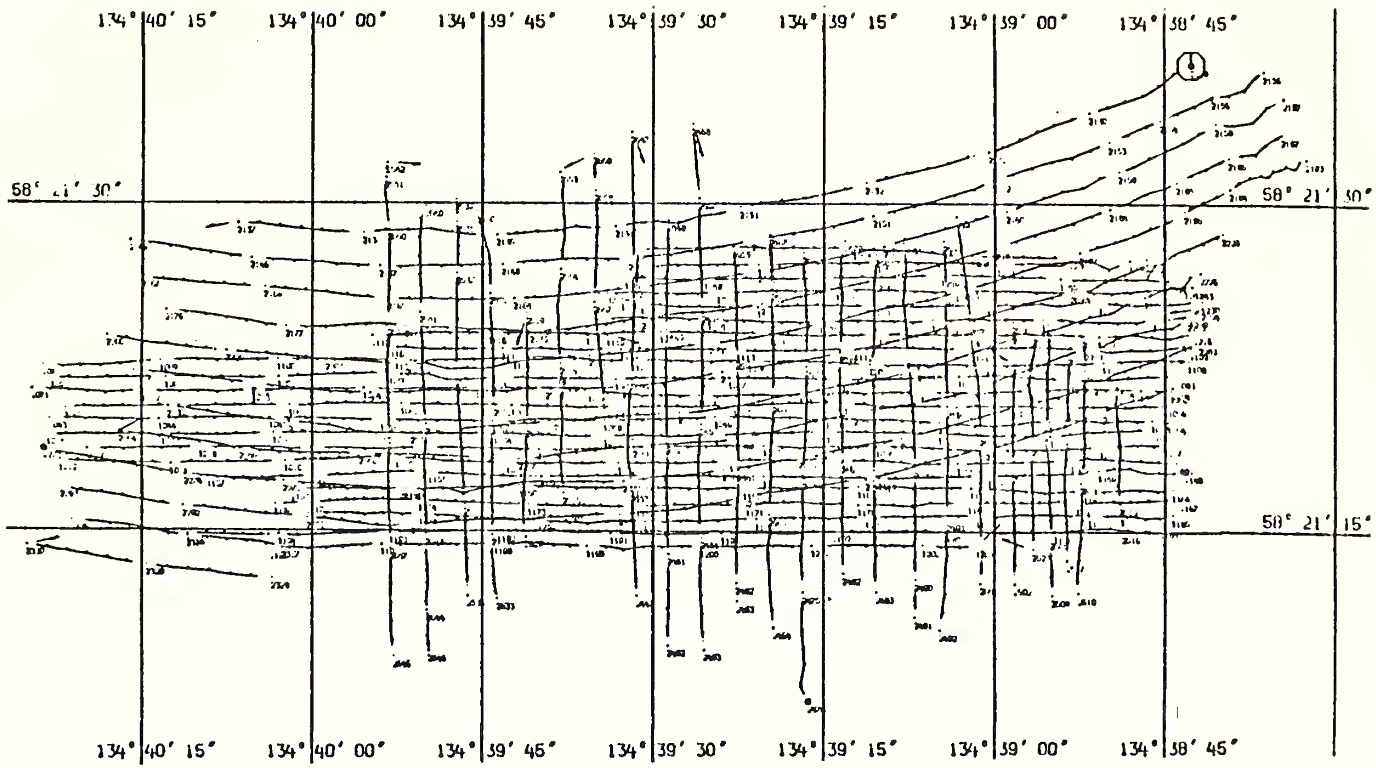


Figure 4.--Position plot Area One.

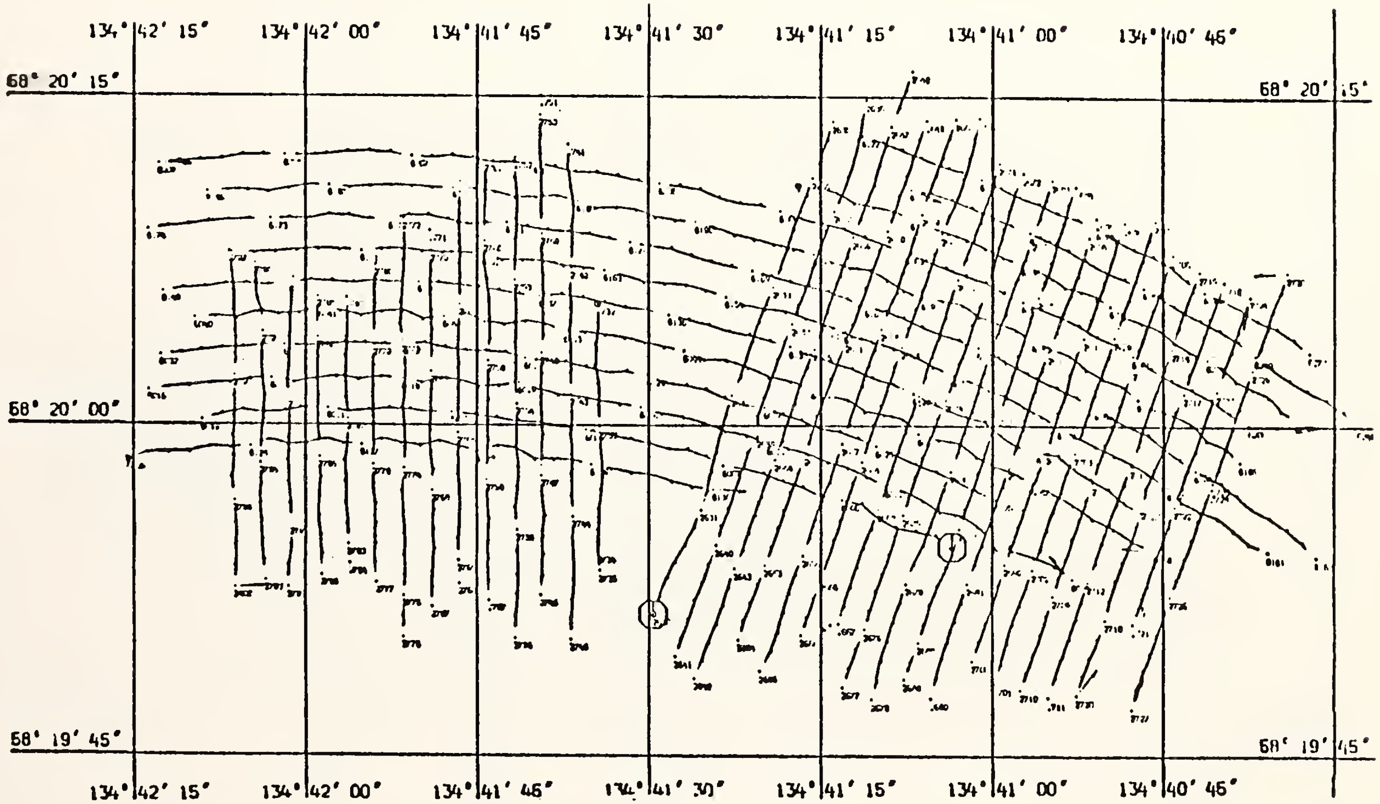


Figure 5.--Position plot Area Two.

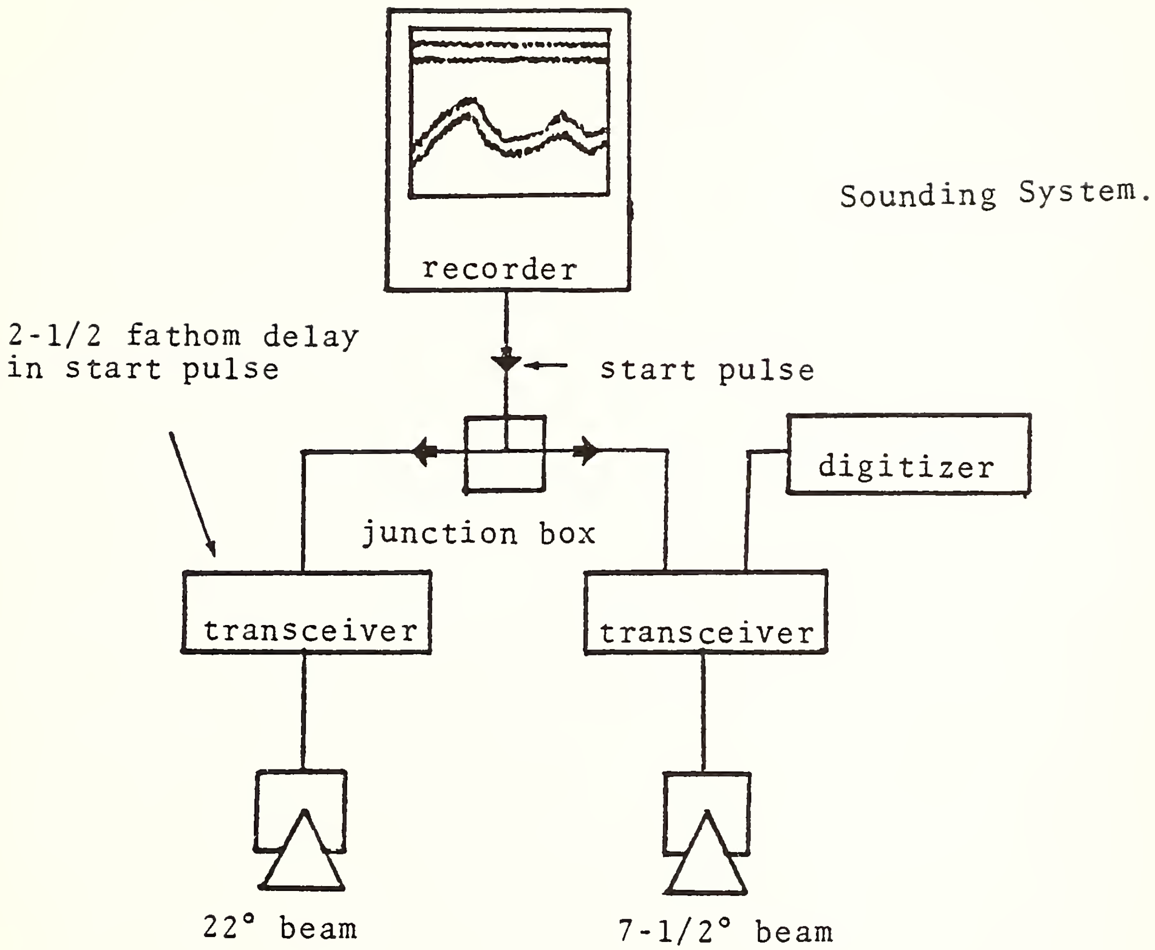


Figure 6.--Design of the 7.5° and 22° system.

Table 1.--Recorder characteristics

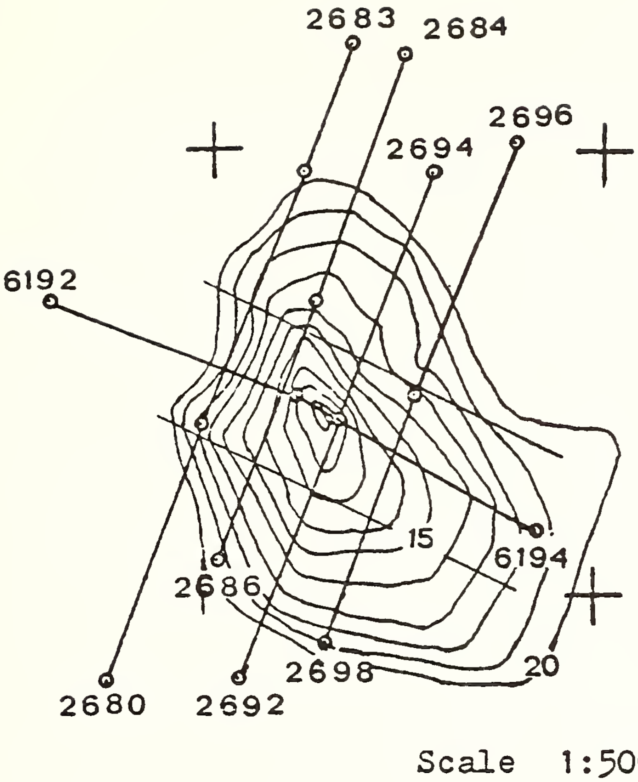
	7.5° System*
Recorder:	Range--400 ft/200 fathoms
	Phasing--100 ft/50 fathoms per 6.5-inch scale
Transducer:	Frequency--100 kHz
	Beam width--7.5° to 6-dB level
Digitizer	
	22° System*
A transceiver and transducer were added to the 7.5° system.	
Transducer:	Frequency--100 kHz
	Beam width--22° to 6-dB level
	25° by 60° System†
Recorder:	Range--1 ft/250 fathoms
	Phasing--50 ft/50 fathoms per 6.25-inch scale
	Chart speed--60 inches/hr, 120 inches/hr
Barium titanate	
Transducer:	Frequency--21 kHz
	Beam width--25° fore and aft to 6-dB level, 60° athwart ships

*General characteristics:

Pulse repetition rate--feet (6/sec), fathoms (2/sec)
Calibrated velocity--4,800 ft/sec

†General characteristics:

Pulse repetition rate--feet (10/sec), fathoms (1.66/sec)
Calibrated velocity--4,800 ft/sec



1 fathom contours
7⁰ beam
correctors applied

Position Plot (45-meter line spacing)
Top Portion of Eleven Fathom Peak
from Northeast Corner of Area Two

Figure 7.--Sounding lines over 11-fathom peak.

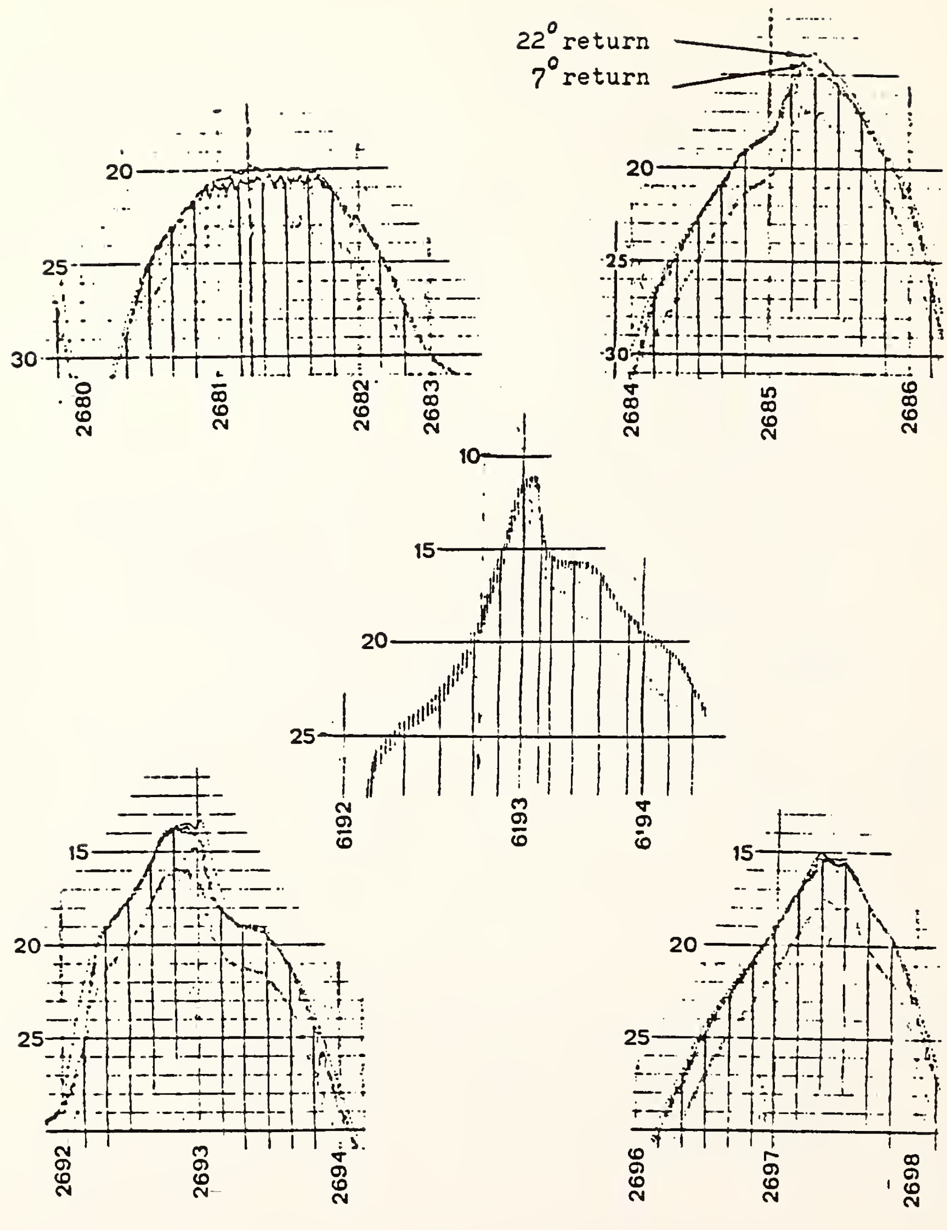


Figure 8.--7.5° and 22° beam sounding profiles on 11-fathom peak.

Figure 9 illustrates a broad 3-fathom deep peak from Area One, with sounding lines at 20-m spacing. The dual sounding profiles are from the 7.5° beam, and the 25° by 60° beam. In this case, the peak is not well isolated by narrow versus wide depth differences. Sounding lines numbered two and three contain little indications of slope. The 3 to 4 fathoms of water have reduced the bottom coverage and the effectiveness of the dual beam system.

Small-Scale Features

The usefulness of a narrow versus wide beam sounding system is more apparent in the following figures of the profiles over features with horizontal extent less than 50 m. The potential for large slope angles is naturally greater with small features of any significance, and the area of "zero difference" over the peak is small.

Figure 10 shows a small, 3-fathom peak approximately centered between 20-m line spacing sounding lines. At this depth the 60° beam was supplying nearly 100 percent coverage. The narrow beam did not see the feature.

Figure 11 illustrates that even in 5- to 10-fathom water, the narrow versus wide beam data may be useful in locating and determining the least depth of small features. The bottom coverage was very limited (22° beam = 4 m), but narrow versus wide depth differences are visible on line 2 and in line 3 on the steep slopes of the small peak.

Figure 12 indicates a wide beam return. The wider hyperbolas of the wide beams strongly substantiate the narrow beam returns, which might have missed the scanner's attention. When surveying at speeds between 8 and 15 knots, the narrow beam was transmitting at intervals of 7 to 13 feet. Therefore, features of substantial height and horizontal extent may be indicated by only a couple of narrow beam marks on the analog trace. These isolated narrow beam marks may easily be mistaken as "strays." The wide beam extends the small-scale feature returns to a point where they are more difficult to ignore. The difference in narrow versus wide depths at the peak apex indicates this was not the peak's least depth.

Peak Detection

Evaluating the benefits of increased bottom coverage by using a wide beam is generally difficult to quantify because of the problem of spherical spreading and its dependence on water depth. The detection of features between sounding lines which were not indicated by the narrow beam would be such a measure. Isolated small-scale features similar to those in figures 10, 11, and 12 were disappointingly scarce. The narrow beam analogs contained three isolated peaks of less than 50-m horizontal extent and of any significant height. The wide beams reflected five isolated small-scale peaks that were not recorded by the narrow beam trace. Figure 10 was one of a group of three small-scale peaks that were 2- to 3-fathoms high and less than 20 m in extent in a fairly flat area (58°21'15"W, 134°38'52"N, Area One) of 10- to 15-fathoms deep. These peaks were developed by a second set of north-south sounding lines at

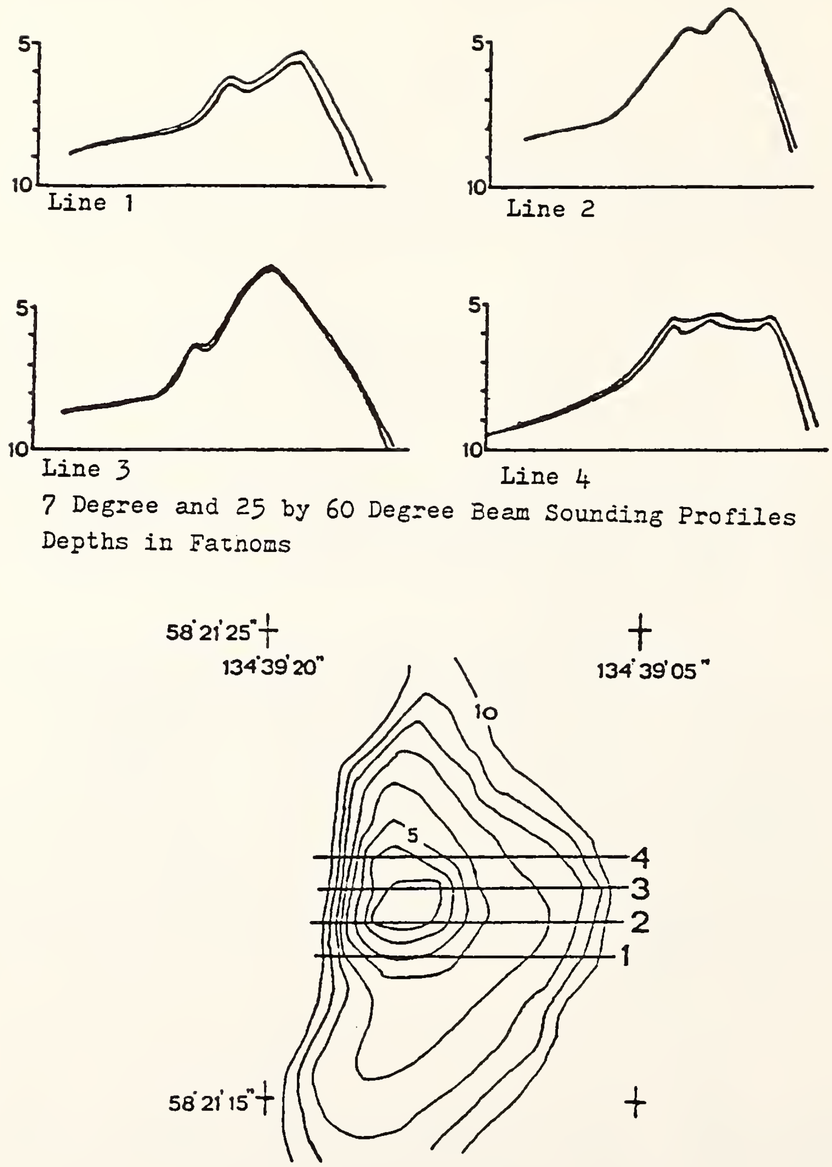


Figure 9.--Top portion of 3-fathom peak from Area One.

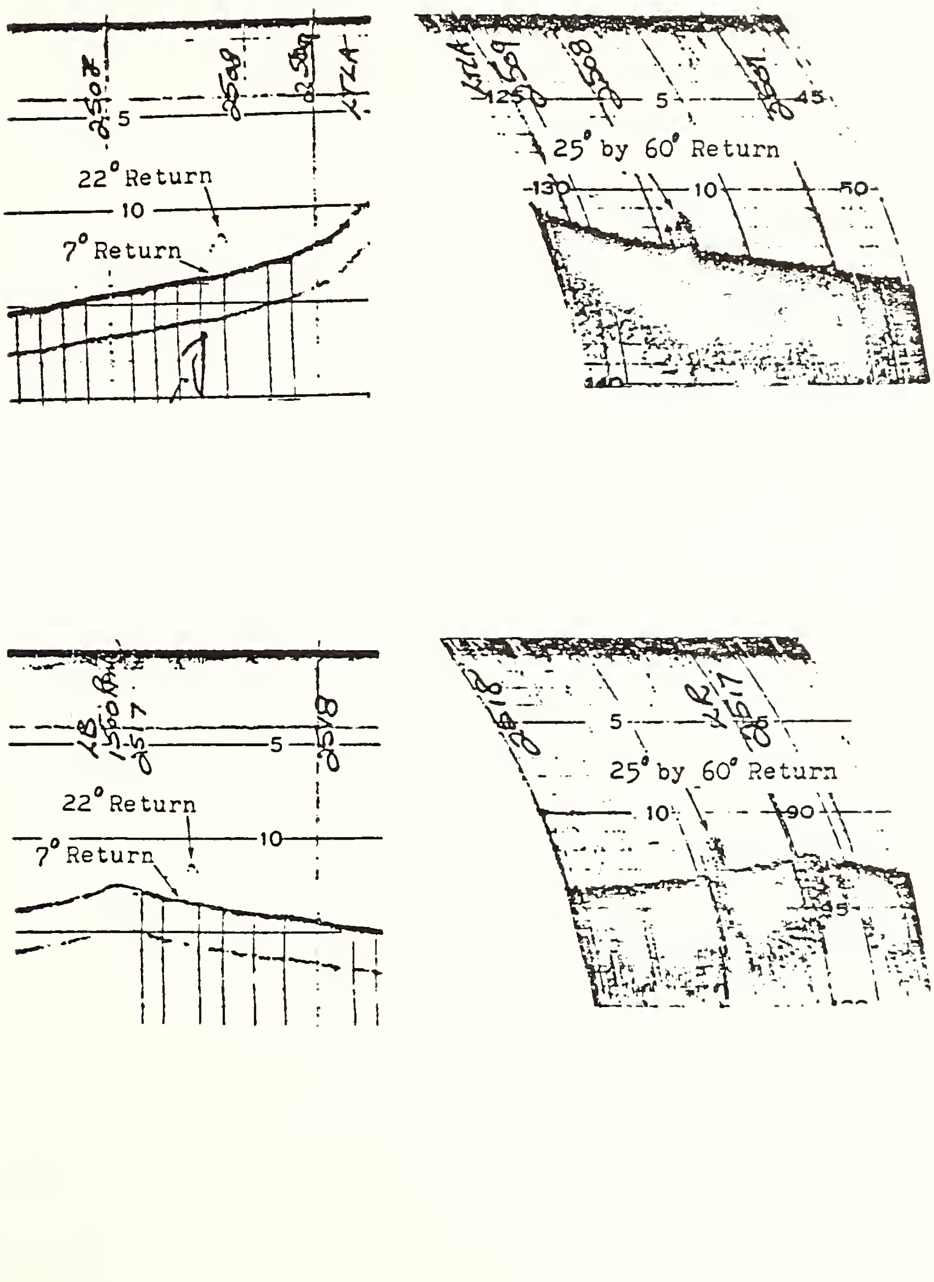


Figure 10.--Small peak between two 20-meter line spacing sounding lines.

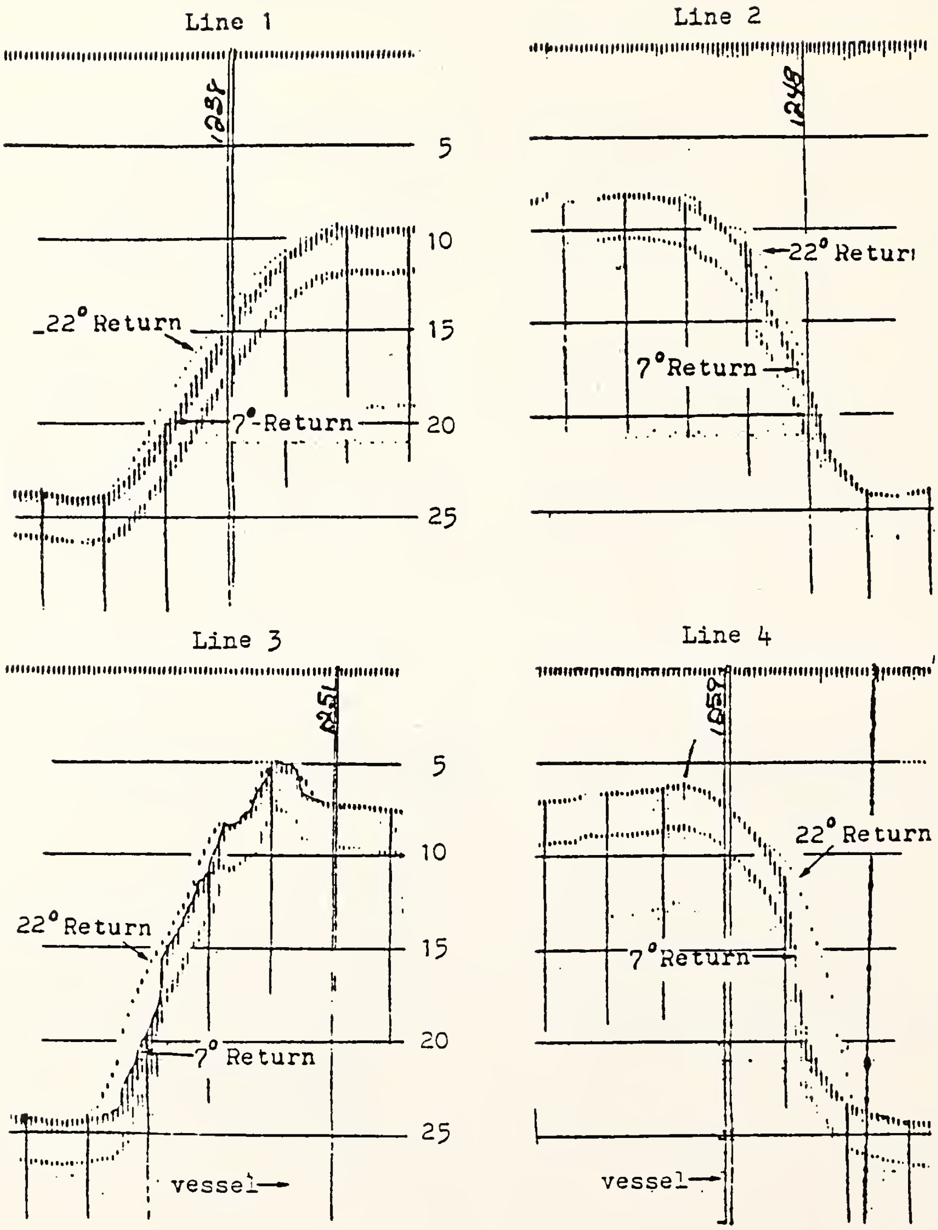


Figure 11.--Narrow vs. wide beam on steep slopes; 20-meter line spacing.

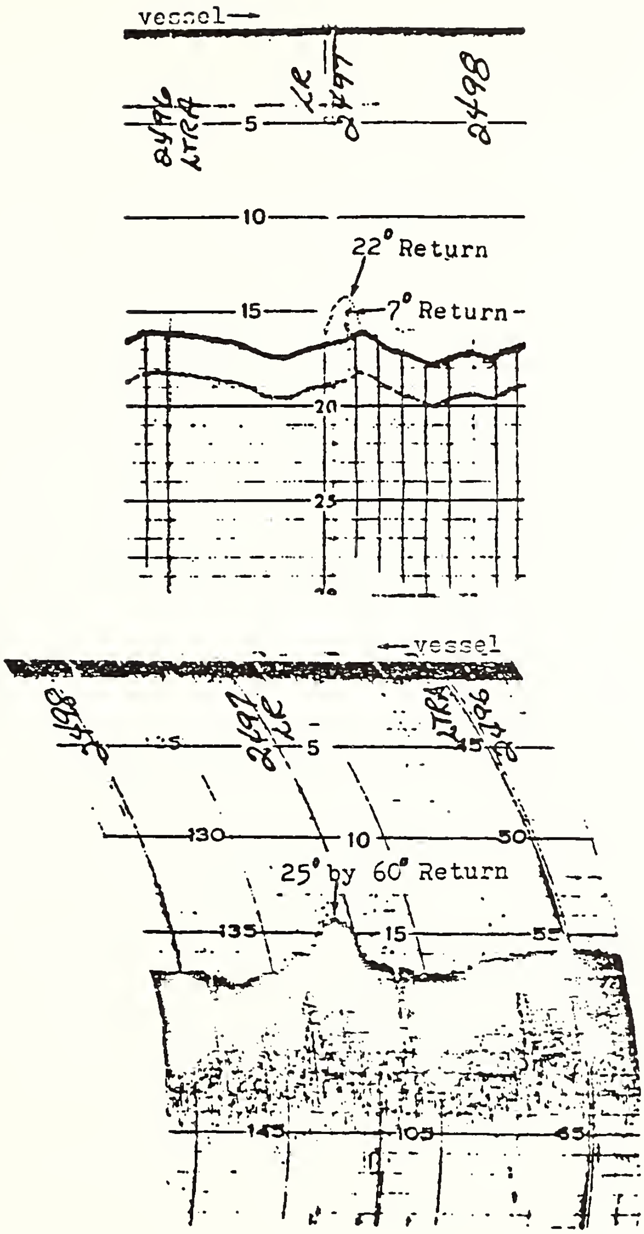


Figure 12.--Wide (60°) beam return substantiates 22° and 7.5° returns on same feature.

20-m spacing and were still not picked up on the narrow beam trace.

The sample size is too small to make any quantitative estimate of the wide beam's potential to reflect features totally absent on the narrow beam trace. The feature discoveries that could be attributed solely to the wide beam's side-looking abilities were a significant number because the total dual beams' hydrography amounted to only 60 nautical miles or 1 typical launch working day.

The average launch speed was 8 knots, or about 4 meters per second. The pulse repetition rate at this speed was fast enough to supply overlapping insonified bottom areas for the wide beams, up to a depth of 2 or 3 fathoms. The 7.5° beam began to lose overlapping areas in depths less than 9 fathoms due to its smaller insonified bottom area. The wide beam of a dual beam system decreases the problem of maintaining overlap between pulses in very shallow water.

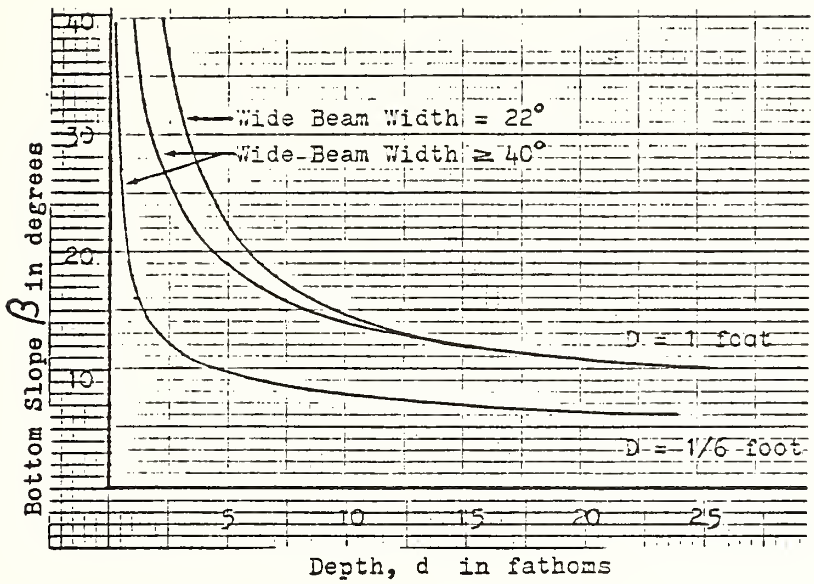
Peak Isolation

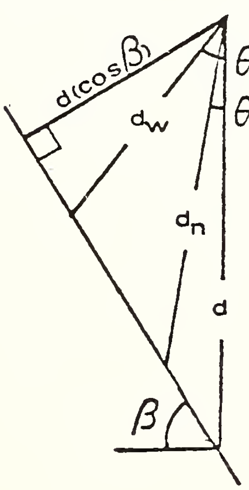
The narrow versus wide beam depth differences may assist the hydrographer by indicating the sounding line has passed within some limits of the peak's apex. The difference between the narrow and wide beam depths goes to zero over the peak apex. To maintain positional accuracy, the least depth would have to come from the narrow beam trace, unless the water was very shallow. The previously presented profiles over individual features demonstrated cases where the sounding line obviously did not find a least depth, as well as cases where the sounding line displayed a "zero difference" and must have crossed near the apex. Theoretically a "zero difference" while developing a feature would be a point directly over the least depth. The resolution of the echo sounder limits the minimum depth difference that is discernible before it is considered zero.

For the 7.5° and 22° system used in this project, a 1-foot difference in narrow versus wide beam depths was visible while using the fathom scale. This resolution is not considered overly optimistic when both narrow and wide beam traces are on the same recorder. The timing errors will affect both the traces equally when they are on the same recorder. A small difference in the wide and narrow beam traces is readily discernible if the wide beam directly overlays the narrow beam trace, and if it is recorded with a lighter mark intensity.

The minimum bottom slope required at a particular depth to generate a 1-foot difference between the 7.5° beam and the 22° beam is plotted in figure 13. Features with slopes and depths that plot above this curve will have some degree of peak isolation using narrow and wide beam depth differences. Also plotted is the dividing line for a 40° wide beam with minimum discernible depth differences of 1 foot. The minimum discernible depth difference could have been decreased to one-sixth foot by operating the system using the feet scale.

The 1-foot dividing line for features that will develop narrow versus wide beam depth differences and allow some degree of peak isolation agrees





D = minimum discernable difference narrow versus wide depths

$d_n = d \cos\beta / \cos(\beta - \theta_n)$

$d_w = d \cos\beta / \cos(\beta - \theta_w)$

$D = d_n - d_w$

d_w = wide beam depth

d_n = narrow beam depth

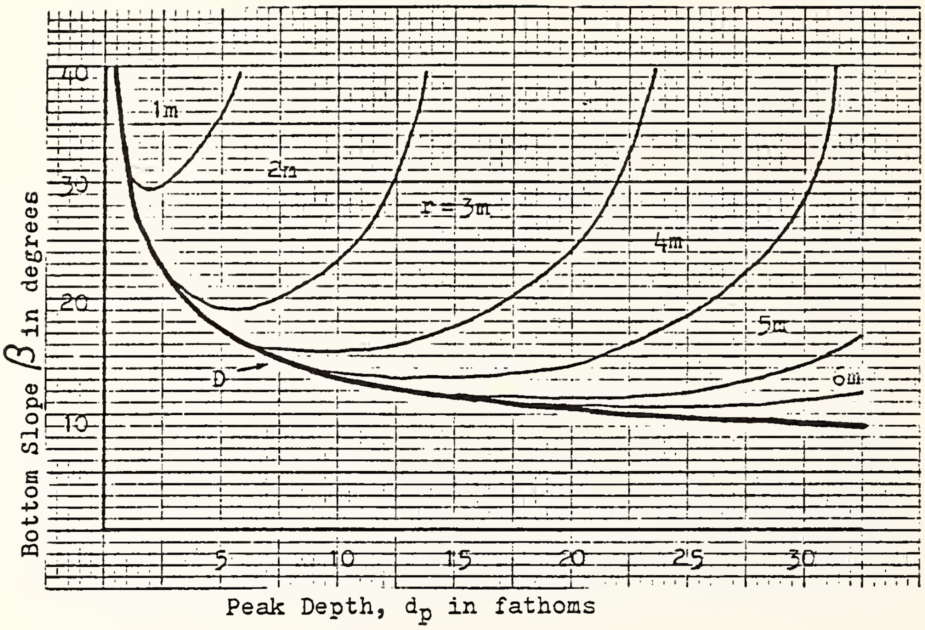
β = bottom slope

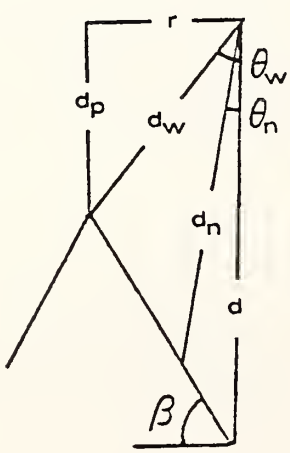
θ_n = 1/2 angle narrow beam =

θ_w = 1/2 angle wide beam

d = true depth

Figure 13.--Bottom slope and depth to obtain minimum depth difference of 1 foot and one-sixth foot between the narrow and wide beams.





D = minimum discernable difference narrow versus wide depths 1/6 fathom

r = radius of peak isolation area in meters

d = true depth

d_p = peak depth

d_w = wide beam depth

d_n = narrow beam depth

β = bottom slope

θ_n = 1/2 angle narrow beam

θ_w = 1/2 angle wide beam

Figure 14.--Peak isolation for cone-shaped features.

with the project data. For example, figure 8 has 15° to 22° slopes and depths of 10 to 15 fathoms near the peak. Sounding lines adjacent to the peak indicate that the apex was not found. Figure 9 has slopes averaging about 10° and depths of 2 to 5 fathoms, which is below the useful peak isolation line. The large-scale features had average bottom slopes across their apex in the 5° to 15° range. The significant small-scale features typically had slopes greater than 20°, which requires depths of at least 4 fathoms for peak isolation.

Assuming cone-shaped features, the degree of peak isolation has been plotted in figure 14. This illustrates the diameter of the circular area of "zero difference" over the cone-shaped feature for a 7.5° narrow beam versus a wide beam of at least 40°. The features on this figure are plotted against peak depth. Figure 14 illustrates the peak isolation limits for a minimum discernible difference of 1 foot.

The narrow versus wide beam depth difference can assist the hydrographer in isolating and determining a least depth. The feature to be developed may be run, using a line spacing based on a reasonable wide beam's bottom coverage. For example, the spherical spreading of a 30° beam is not excessive. A 30° beam will indicate shoals within its insonified area that are greater than 5 percent of the vertical depth. Also, the 30° beam has an insonified area that is still 5 m in diameter in only 5 fathoms of water (fig. 2). The narrow versus wide beam depth differences will isolate the feature's peak to a degree that, if necessary, is more reasonable to further develop using only the narrow beam.

CONCLUSIONS

The negative effects of the wide beam's poor horizontal resolution and the degree of wide beam depth error relative to a 7.5° narrow beam were plotted for the two project areas. The plots illustrated the necessity of a narrow beam echo sounder for accurate depth determinations. The results confirm the usefulness of side-looking abilities of the wide beam echo sounder, in spite of the problems with spherical spreading. The sample size of the features detected with the wide beams was too small to quantify the usefulness of the 60° transverse beam relative to the 22° beam. The wide beam trace was found to emphasize the narrow beam profiles over small features that may have missed detection when scanned.

A useful ability of peak isolation is exhibited by the narrow versus wide beam depths over feature peaks. This requires a visible narrow versus wide beam depth difference in the recorded traces near the peak's apex, which is a function of the bottom slope and peak depth. A model using cone-shaped features indicated the degree of peak isolation.

PART II

INTRODUCTION

This portion of the paper details the field use of the described dual

beam 100-kHz system. This system was used as the standard survey system on a NOAA Ship RAINIER type 1 survey launch for the entire 1979 field season.

During this time, work was accomplished in three separate geographical areas, each with different types of bottom topography. The first area was in southeast Alaska, characterized by steep slopes and deep water with rocky peaks and irregular bottom topography. The second area, in Cook Inlet, Alaska, was characterized by relatively shallow water with gentle slopes and flat muddy and sandy bottom topography. Some water areas of Cook Inlet were littered with large submerged boulders which were very difficult to locate in the discolored water and rapid currents. The third area was in the Hawaiian Islands, characterized by steep slopes, deep water, and a slightly irregular bottom topography.

OPERATING METHOD

The dual beam system was used in the overlapping trace mode for the entire year. By delaying the wide beam transmit pulse, this system had the capability of separating the two bottom return traces on the recorder by up to 2.5 fathoms. Nevertheless, it soon became evident that, although separating the traces did allow a direct comparison of the two returns, the differences in depths were usually too small to be obvious. However, joining the two returns to present one trace on a flat bottom made the slightest differences obvious. Differences in intensity of the two traces allowed easy recognition of the wide beam return, and when any separation occurred, the wide beam trace would always be the upper trace. As the system was wired to digitize the narrow beam return, it also provided that information to the data acquisition system and allowed data acquisition to proceed as usual with the additional wide beam information used for reference only.

Under most situations it was possible for the officer-in-charge (OIC) of the sounding launch to evaluate the wide beam information while the launch was collecting data. It was then possible to run more lines while in the area if this was necessary. In some cases it was necessary to rescan the fathogram near a feature after the rough sounding plot was plotted and contoured to determine if additional work was necessary. When the system was used for developments it was possible to state with increased confidence, that the least depth was indeed obtained if the line spacing was reasonable and the bottom trace at the least depth did not separate into two traces.

RESULTS

In general the additional information gained by using the wide beam system, although helpful at times, was not as productive as had been hoped. It was most useful in southeast Alaska with the rugged steep bottom topography. One fairly substantial submerged peak was developed that might not have been noticed using only a narrow beam. The biggest benefit was the wide beam system's aid in finding least depths over peaks and providing immediate feedback as to the presence of steep-sloped irregular features. However, the value of the system in Cook Inlet was minimal. The relatively shallow water

(less than 30 fathoms) and flat bottom did not reveal much to the 22° beam width. The appearance of a boulder on the fathogram was still only a matter of chance or the result of an intense development of a suspect area. No existing system would be adequate for this very difficult area, given present line-spacing specifications. The Hawaiian project also provided little useful information. Although near shore areas were sometimes littered with coral heads, the water depth was not great enough for the 22° beam to be a definite asset. The deeper water topography was uniform and very steep. The benefit of the system in these depths again was not substantial.

RECOMMENDATIONS

The number of possible sounding system configurations is varied. Each system alternative is best suited for a particular type of operation (charting, bathymetry, searching) and is most effective when operating in a particular bottom topography (steep, rocky, muddy, flat). A dual beam system has certain advantages that should make it a viable alternative, along with swath and side scan systems, when the next generation of sounding system is being developed. If such a system is considered, it is felt, from the experience gained this year, that the following configuration would be desirable as a general hydrography system:

(1) Two beam widths — 7.5° and 55°

(2) Two frequencies — 100 kHz and 20 kHz (low)

(3) Simultaneous sounding and recording with independent gain control

(4) Digitization of only narrow beam

(5) Heave-Roll-Pitch correction capability

The advantages of such a system are several. The dual beam allows a relatively accurate measurement of the depth immediately below the sounding launch. It also provides the added benefit of letting the officer-in-charge know immediately that shoaler depths are in the near vicinity. The 55° beam width allows bottom isonification of an area approximately 100 percent of the depth in diameter. It also should detect anything in that area that extends more than 10 percent of the depth above the bottom. A beam wider than this would allow a substantial increase in the size of an object that can remain hidden because of spherical spreading.

The present standard for NOS' 7.5° sounding system is the 100-kHz frequency which provides a good return from most types of bottom consistencies to approximately 150 fathoms. The low frequency (approximately 20 kHz) should be low enough to sound through weeds and kelp if necessary, but not low enough for subbottom investigations. The idea of gathering the subbottom information sounds desirable in theory, but many practical obstacles exist between the theory and actually gathering useable information efficiently.

Simultaneous sounding and recording on the fathogram would allow a direct and immediate comparison of the two types of information. If the digitizer

is keyed by the narrow beam only and if the two beams have separate gain and intensity controls, most of the confusion that might arise in trying to interpret the two traces can be eliminated.

A heave-roll-pitch device would make the narrow beam information more accurate as well as reducing the effort needed to rescan and correct the data. In irregular areas corrections are not now possible and in flat areas extra effort is necessary.

Any new system has disadvantages. This system is more complex electronically. This is a fact which has to be taken into consideration when planning maintenance and repair. In addition, the theory of its operation is more complex and requires that the operators be trained to use the equipment and interpret the results. Similarly, the verification and quality control personnel must be trained to understand the new system. Resistance within the organization to the new equipment might be encountered on a personal level as with any change. This system might appear more expensive at a glance than the more simple versions. However, these economic considerations are relative and should be weighted against all the other alternatives, i.e., the priority of increased accuracies against any additional cost. The dual beam system would also result in more work during data collection. It would be one more thing on which to concentrate in an environment that is already fairly hectic and demanding at times.

CONCLUSION

The dual beam echo sounder appears to be well-suited for filling the void between narrow beam sounding and swath or scanning sounding systems in shallow water launch hydrography. The abilities and procedures with narrow beam echo sounding are maintained, while adding the beneficial factors inherent in a wide beam system. The wide beam trace becomes a familiar and easy-to-operate, descriptive tool for the hydrographer.

DISCUSSION

Lt. Crowell: I notice that you seem to emphasize that the dual beam width sounding system works better in deep water. However, the place you really want to detect an extra shoal sounding is in shallow water because nobody has a draft of 60 fathoms. The only people who would benefit from the system would be submarines. I was just wondering, is it worthwhile to use the system in shallow water, which is where the need is to detect any rocks or anything?

Lt. Anderson: In really shallow water, where you are talking about running aground on something, it's not useful. With the 55° beam you're getting more coverage, but I think there's not a system around today that really works well--that will work in really shallow water and give you everything, including the side scan sonar. Shallow water is something within the range of the systems that we're using now--less than 150 fathoms.

Lt. Cdr. Seidel: I'd like to add that the work that I was involved with was in the range of 15 to 30 fathoms. Within that range, there was useful information to about 5 fathoms. Above 5 fathoms, that is shallower than 5 fathoms, the system seemed not to register anything useful. This shallow water area covers a lot of our hydrographic work.

Cdr. Richards: What was the rationale you went through to arrive at the figure of 55° as the optimum wide beam?

Lt. Anderson: I was afraid somebody was going to ask that. The *Hydrographic Manual* states that in depths in excess of 20 fathoms all shoal indications that rise more than 10 percent above the surrounding depths should be investigated. It was thought that a 55° beam width would discover many of these features. Another reason is that it insonifies an area of the bottom the diameter of which is 100 percent of the depth; an easy figure for the officer-in-charge to remember.

Mr. Westbrook: On Wednesday, Dr. Lloyd Huff will give a paper titled "Study of Future Depth Recorder Requirements." This paper has a direct correlation with the talk we have just heard. It's a very interesting subject. In addition, you'll be able to see how NOS is developing information in this area.

VECTOR DERIVATION OF TRILATERATION ACCURACY AND COMPARISON OF ERROR DIFFERENCES

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ABSTRACT. This paper summarizes the vector derivation of trilateration accuracy of an error ellipse and compares the error differences for the ellipse, one vector of the error ellipse, and the resultant of two range error terms. The results indicate that when only one vector is used, the standard deviation depends on the angle of cut and correlation. When both the major and the minor axis of the error ellipse are used, the standard deviation depends on the angle of cut but is independent of correlation. The resultant of two range error terms leads to erroneous results. The best technique appears to be calculations based on both diagonals of the error ellipse and related to RMS radial errors.

DERIVATION OF ELLIPTICAL ERROR TERMS

If range-only measurements are taken to two shore targets, then the errors may be expressed as an error parallelogram, error ellipse, or an error circle that contains one sigma or about 68 percent of the measurements as depicted in figure 1.

The two error terms σ_{r1} and σ_{r2} are separated by the angle α to the two targets. The vectors a and b are both perpendicular to σ_{r1} and σ_{r2} such that the same angle α separates a and b. The vector V represents a maximum in the direction of the major axis of the parallelogram ($\alpha<90^0$), and the vector W represents a maximum in the direction of the minor axis. For different angles, i.e. $\alpha<90^0$, then vector W would be greater than vector V. The resultant error term, due to the major and minor axis of the parallelogram, may be expressed as:

$$\sigma_z^2 = \sigma_V^2 + \sigma_W^2 \qquad (1)$$

where σ_z^2 = Resultant variance of the parallelogram for targets 1 and 2;

σ_V^2 = Variance of the major axis of this parallelogram;

σ_W^2 = Variance of the minor axis of this parallelogram.

$$\sigma_V^2 = a^2 + b^2 + 2\ ab \cos\alpha \qquad (2)$$

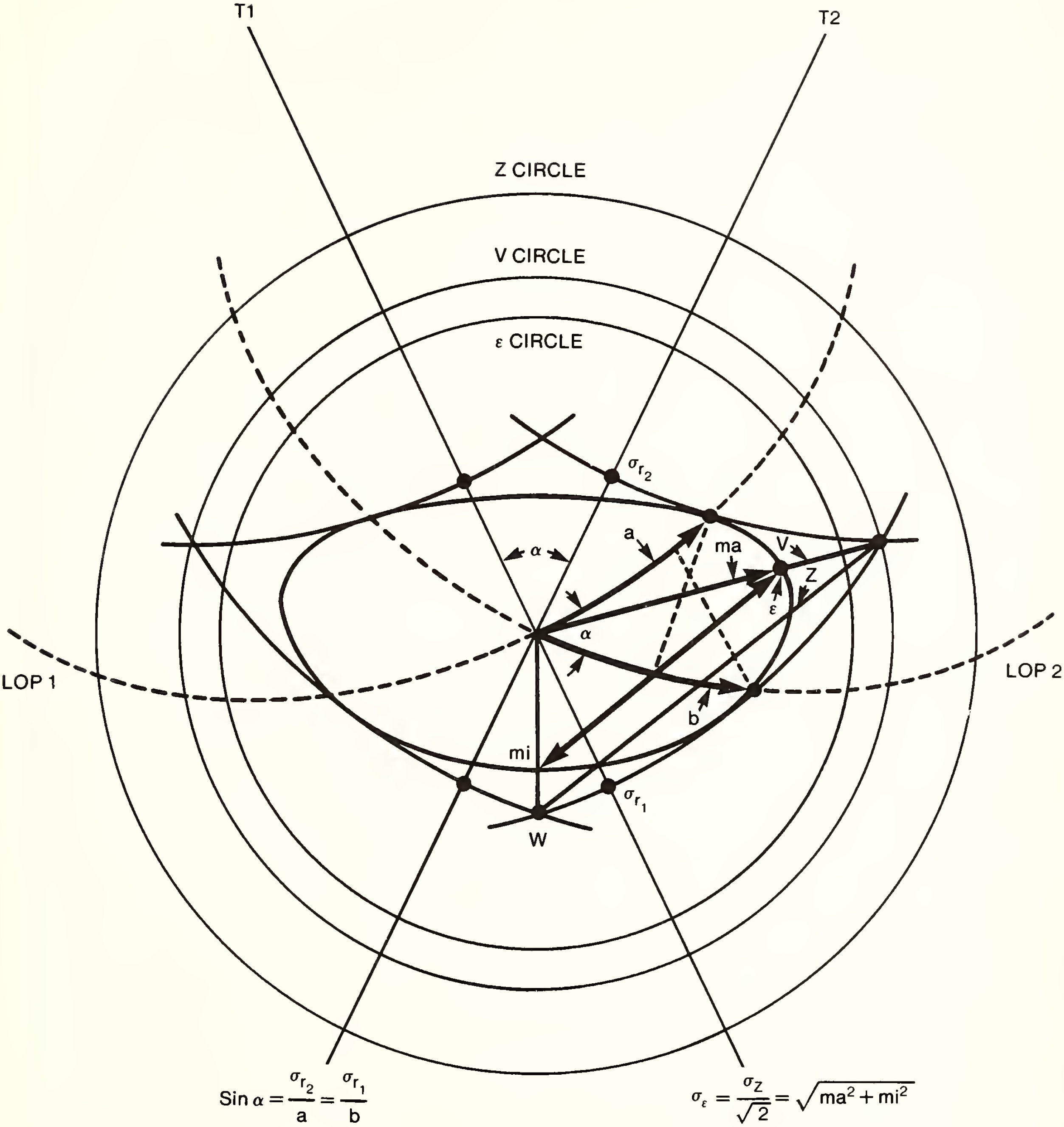

Figure 1.--Trilateration by ranging to two targets.

and the vector W is expressed as

$$\sigma_W^2 = a^2 + b^2 - 2\,ab\cos\alpha \quad . \tag{3}$$

Therefore
$$\sigma_z^2 = 2a^2 + 2b^2 \tag{4}$$

a and b are related to α as follows:

$$\sin\alpha = \frac{\sigma_{r2}}{a} = \frac{\sigma_{r1}}{b} \tag{5}$$

and by substitution:

$$\sigma_z^2 = \frac{2\sigma_{r2}^2}{\sin^2\alpha} + \frac{2\sigma_{r1}^2}{\sin^2\alpha} \tag{6}$$

therefore
$$\sigma_z = \frac{\sqrt{2}}{\sin\alpha}\sqrt{\sigma_{r1}^2 + \sigma_{r2}^2} \tag{7}$$

and for $\sigma_{r1} = \sigma_{r2}$, like radar or interrogators:

$$\sigma_z = \frac{2\sigma_{r1}}{\sin\alpha} \tag{8}$$

where σ_z = Resultant standard deviation of the parallelogram for two targets

$\sigma_{r1} = \sigma_{r2}$ = Standard deviation in range for each target

α = Angle of cut between the two targets.

This result is depicted as the Z circle on figure 1. These values may be related to elliptical values by dividing by the $\sqrt{2}$ as the major and minor axis of the ellipse differ by this factor from the parallelogram values.

$$\sigma_\varepsilon = \frac{\sigma_z}{\sqrt{2}} = \sqrt{\sigma_{ma}^2 + \sigma_{mi}^2} \tag{9}$$

where σ_ε = Standard deviation or root mean square (rms) deviation from the mean of the ellipse enclosed within the parallelogram.

σ_z = Standard deviation of the parallelogram

σ_{ma} = Standard deviation of the major axis of the ellipse

σ_{mi} = Standard deviation of the minor axis of the ellipse

Also, since the major and minor axis of the ellipse differ by $\sqrt{2}$ from the parallelogram values, the standard deviation may also be expressed as:

$$\sigma_\varepsilon = \frac{\sigma_z}{\sqrt{2}} = \frac{\sqrt{2}\,\sigma_{r1}}{\sin\alpha} \tag{10}$$

where symbols are as previously expressed.

Some typical results for the ellipse and parallelogram for various angles are shown in table 1.

Table 1.--Standard deviation of the error ellipse and parallelogram for various angles of cut

α	σ_E	σ_Z	Normalized
10^0	8.15	11.52	5.76
20^0	4.14	5.85	2.93
*30^0	2.83	4.0	2.0
40^0	2.2	3.11	1.56
50^0	1.85	2.61	1.31
60^0	1.63	2.31	1.16
70^0	1.51	2.13	1.07
80^0	1.44	2.03	1.02
90^0	1.41	2.0	1.0
100^0	1.44	2.03	1.02
110^0	1.51	2.13	1.07
120^0	1.63	2.31	1.16
130^0	1.85	2.61	1.31
140^0	2.2	3.11	1.56
*150^0	2.83	4.0	2.0
160^0	4.14	5.85	2.93
170^0	8.15	11.52	5.76

* = Factor of 2 from error at 90^0

$\sigma_1 = \sigma_2 = 1$

COMPARISON OF ERROR DIFFERENCES

For comparison purposes the differences for an ellipse, parallelogram, one vector of the parallelogram, and the resultant of two range errors are calculated.

1. Error ellipse

$$\sigma_E = \frac{\sqrt{2}\,\sigma_1}{\sin\alpha} \tag{11}$$

2. Parallelogram

$$\sigma_Z = \frac{2\,\sigma_1}{\sin\alpha} \tag{12}$$

3. One vector of the parallelogram

$$\sigma_{V_1} = \frac{\sqrt{2}\,\sigma_1}{\sin\alpha}\sqrt{1 \pm c\cos\alpha} \tag{13}$$

where for maximum values the sign is + for angles $\leq 90^0$ and − for angles $>90^0$. For uncorrelated signals, c = o and this equation reduces to that of the error ellipse.

4. The resultant of two range errors

$$\sigma_R = \sqrt{2}\,\sigma_1\sqrt{1 \pm c\cos\alpha} \tag{14}$$

For maximum values, the sign is + for angles $\leq 90^0$ and − for angles $>90^0$.

These error difference comparisons are shown in table 2.

At 90^0 angle of cut, the results for two range errors equals any one vector of the error parallelogram and the error ellipse, whereas parallelogram values for the radius of the Z circle are $\sqrt{2}$ times greater.

As the angle of cut deviates from 90^0, the + and − parallelogram and ellipse terms begin to deviate, depending on correlation and angle of cut. For 30^0 the uncorrelated two range errors are the same as at 90^0. The + and − vector errors of the parallelogram have both increased to 2.83 and the parallelogram Z values to 4 which is a factor of 2. The elliptical error has also increased to 2.83 which is a factor of 2 and which agrees with the uncorrelated + and − vector parallelogram values.

For 30^0 the correlated $\pm$ values for two range errors are 1.93 and 0.52 the correlated $\pm$ values for the vectors of the parallelogram are 3.86 and 1.04. Values for the parallelogram Z factor and error ellipse are unchanged at 4.0 and 2.83.

If these values are compared with the 150^0 angle of cut values which are equally distant from 90^0 as from 30^0, then for two range errors the uncorrelated

Table 2.--Comparison of error differences

α	C	σ_{ε}	σ_{z}	σ_{V+}	σ_{V-}	σ_{R+}	σ_{R-}
10^0	0	8.15	11.52	8.14	8.14	1.41	1.41
	1			11.47	1.0	2.0	0.17
20^0	0	4.14	5.85	4.13	4.13	1.41	1.41
	1			5.76	1.02	1.97	0.35
30^0	0	2.83	4.0	2.83	2.83	1.41	1.41
	1	2.83	4.0	3.86	1.04	1.93	0.52
40^0	0	2.2	3.11	2.20	2.20	1.41	1.41
	1			2.92	1.06	1.88	0.68
50^0	0	1.85	2.61	1.85	1.85	1.41	1.41
	1			2.37	1.10	1.81	0.85
60^0	0	1.63	2.31	1.63	1.63	1.41	1.41
	1			2.00	1.15	1.73	1.0
70^0	0	1.51	2.13	1.50	1.50	1.41	1.41
	1			1.74	1.22	1.64	1.47
80^0	0	1.44	2.03	1.44	1.44	1.41	1.41
	1			1.56	1.31	1.53	1.29
90^0	0	1.41	2.0	1.41	1.41	1.41	1.41
	1	1.41	2.0	1.41	1.41	1.41	1.41
100^0	0	1.44	2.03	1.44	1.44	1.41	1.41
	1			1.31	1.56	1.29	1.53
110^0	0	1.51	2.13	1.50	1.50	1.41	1.41
	1			1.22	1.74	1.47	1.64
120^0	0	1.63	2.31	1.63	1.63	1.41	1.41
	1			1.15	2.0	1.0	1.73
130^0	0	1.85	2.61	1.85	1.85	1.41	1.41
	1			1.10	2.37	0.85	1.81
140^0	0	2.2	3.11	2.20	2.20	1.41	1.41
	1			1.06	2.92	0.68	1.88
150^0	0	2.83	4.0	2.83	2.83	1.41	1.41
	1	2.83	4.0	1.04	3.86	0.52	1.93
160^0	0	4.14	5.85	4.13	4.13	1.41	1.41
	1			1.02	5.76	0.35	1.97
170^0	0	8.15	11.52	8.14	8.14	1.41	1.41
	1			1.00	11.47	0.17	2.0
172^0	0	10.16	14.37	10.16	10.16	1.41	1.41
	1			1.0	14.34	0.14	2.0
174^0	0	13.53	19.13	13.53	13.53	1.41	1.41
	1			1.0	19.11	0.10	2.0
176^0	0	20.27	28.67	20.28	20.28	1.41	1.41
	1			1.0	28.65	0.07	2.0

NOTE: 0 Uncorrelated
1 Correlated

values are interchanged from $+-$ to $-+$. Identical results hold true for the $\pm$ vectors of the parallelogram. The parallelogram Z factor and ellipse values, however, remain the same for 150^0 as for 30^0. This indicates that as long as both the $+$ and $-$ parallelogram vectors or ellipse vectors are used, then the resultant radial errors are symmetrical about the 90^0 angle of cut. The elliptical vectors can be derived from the parallelogram vectors, and the elliptical results from the parallelogram results by using the $\sqrt{2}$ factor.

SUMMARY

With all the restrictions for correlated vs. uncorrelated and angle quadrant dependence, it seems that the preferred calculation is the standard deviation or RMS deviation from the mean of the error ellipse, σ_ε. For $\sigma_1 = \sigma_2$ this equation may be expressed as:

$$\sigma_\varepsilon = \frac{\sqrt{2}\,\sigma_1}{\sin \alpha} \tag{15}$$

where σ_ε = Standard deviation of the error ellipse

$\sigma_1 = \sigma_2$ = Standard deviation of each range measurement

α = Angle of cut or intersection of the position lines.

The radial error circle for the error ellipse is less than the standard deviation circle for the parallelogram, less than the circle for the maximum vector of the parallelogram, and larger than the error ellipse, which closely describes the error distribution. These values may therefore be considered conservative as they completely enclose the error ellipse.

NOS HYDROGRAPHIC PROJECT INSTRUCTIONS

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ABSTRACT. The general content and format of hydrographic project instructions for the National Ocean Survey (NOS) have remained essentially the same from 1921 to the present. A recent effort to standardize instruction content and format for usage by both NOS and the U.S. Naval Oceanographic Office has brought about several additions and format changes to the basic instructions. Since the Department of Commerce is directed by section 905, title 3, of the Code of Federal Regulations to provide geodetic, hydrographic, and oceanographic data and services to the Department of Defense in times of national emergency, the need for standardization is apparent.

INTRODUCTION

The format of hydrographic project instructions within NOS (previously the Coast and Geodetic Survey) has remained essentially unchanged as far back as the earliest file copies available from 1921. Although there have been shifts in emphasis and style, the primary areas of concentration have remained consistent. These instructions are, and always have been, applicable only to vessels of NOS. The Naval Oceanographic Office (NAVOCEANO) has issued a dissimilar but equivalent set of instructions called hydrographic survey specifications to vessels under its control. Recently the heads of various agencies including the Oceanographer of the Navy, the Chief of Naval Operations, the Naval Oceanographic Office, and the Director of NOS became concerned that in a time of national emergency the differences in the operating instructions and manuals would cause confusion if NOS and NAVOCEANO tried to work together.

Since section 905, title 3, of the Code of Federal Regulations directs the Department of Commerce to provide geodetic, hydrographic, and oceanographic data and services to the Department of Defense during national emergencies, there was concern over the efficiency and timeliness with which compliance to the directive could be made. Not only have the two organizations used dissimilar operating instructions, they have also had separate operating manuals--NOS recently published the Hydrographic Manual, fourth edition (Umbach 1976), and NAVOCEANO uses the outdated Navy Hydrographic Manual (NAVOCEANO 1961).

HISTORY OF PROJECT INSTRUCTIONS

Historic NOS project instructions range from a very basic outline of required operations to extremely detailed documentations describing the project requirements. The early instructions contain sections on general information, triangulation, topography, hydrography, magnetics, tides, and currents. These sections are not unlike the similar sections in modern project instructions, although the instrumentation differs. It is interesting to note that topography mentioned in these instructions was accomplished by planetable techniques.

In addition, the magnetic observations made special mention of the need for observations to support magnetic compasses aboard ships. Not only have most commercial vessels adopted gyro compasses (many private vessels still rely on magnetic compasses), but the responsibility for this function has been transferred from NOS to the U.S. Geological Survey and NOAA's Environmental Research Laboratories. Magnetic observations are assigned to modern NOS surveys only at the request of either of these two agencies.

The first formalized outline describing the contents of project instructions was contained in the Hydrographic Manual (Special Publication 143), revised edition, by K. T. Adams (1942). It was this manual that added the miscellaneous section to the project instructions. Formal reporting procedures were introduced in that section, thus they are not particularly new requirements. Except for changing the term "triangulation" to control, the content of this section remained the same. The section headed "topography" first mentioned that photogrammetry may be available to define the shoreline for the hydrographer.

In the Hydrographic Manual (Publication 20-2), third edition, by K. B. Jeffers (1960), photogrammetry was added to the topography section in formal recognition of this factor contributing to the finished nautical chart. Both terms were used in heading this section. The only other change was the addition of an oceanography section, reflecting the recognition of the numerous physical factors contributing to the accuracy of sonic depth finders.

In 1976 the Hydrographic Manual, fourth edition, edited by M. J. Umbach (1976) was published. Again, there was some degree of change in the photogrammetry/topography section. In this edition there was no mention of planetable work as being assigned by the project instructions. Thus, the changing requirements of this particular section reflect the evolution of the tools of the hydrographer. The tides section was expanded to include water level measurements to reflect the recent inclusion by NOS of hydrographic survey operations in the Great Lakes. It also allowed for water level correctors in other landlocked bodies of water.

This brief summary of project instructions as they evolved within NOS is by no means comprehensive, but rather offers an overview of general trends within the instructions. Because the instructions often vary as much from set to set as they vary from decade to decade, the present instructions are the results of many years of small changes.

THE WORKING GROUP

In December 1978, the Naval Deputy to the Administrator of NOAA (NAVDEP) requested that NAVOCEANO examine the possibility of standardizing its hydrographic survey specifications with the project instructions of NOS. In January 1979, the NAVDEP further recommended that the Hydrographic Manual, fourth edition, be examined for its applicability to Naval use in lieu of either its present Naval Hydrographic Manual or an updated version of that manual. The two issues were subsequently combined and assigned to NAVOCEANO for resolution.

In response to these and other communiques from the Oceanographer of the Navy, Chief of Naval Operations, Naval Oceanographic Office, and the Director of NOS, a working group was formed from NOS and NAVOCEANO personnel to discuss the ramifications and feasibility of standardizing the two organizations' technical manuals and specifications.

This group recommended the standardization of hydrographic project instructions and began working toward that end. NAVOCEANO had previously reviewed the project instructions of NOS and agreed to adopt that format. The working group initially reviewed and restructured the project instructions and designed a format suitable to the needs of both NOS and NAVOCEANO. Then NOS developed the present hydrographic project instruction structure. Although there may be some additional minor modifications, it is anticipated that these instructions will be approved by both parties.

Concomitant with this discussion and closely related to it was the proposed NAVOCEANO adoption of the Hydrographic Manual, fourth edition. Since techniques vary between NOS and NAVOCEANO operations, NAVOCEANO intends to develop an addendum to the Hydrographic Manual addressing major differences in techniques and terminology peculiar to that agency and instructing the users on how to account for such variances. These differences also can be addressed case by case in the specific hydrographic project instructions.

A final, tentative result of the working group was the proposal that the next (fifth) edition of the Hydrographic Manual be a joint NOS/NAVOCEANO effort. Although this would be a number of years in the future, it would be a further step in standardizing hydrographic procedures in the United States. This joint publication is not without precedent. The Guide on Marine Observing and Reporting (NAVOCEANO et al. 1977) was published jointly by the Naval Oceanographic Office, U.S. Coast Guard, National Oceanic and Atmospheric Administration, and the Hydrographic Center of the Defense Mapping Agency in 1977.

To summarize the actions of the NOS/NAVOCEANO working group, NAVOCEANO tentatively intends to adopt the Hydrographic Manual for its technical manual, but first will prepare an addendum to account for variances in technical procedures and terminology. NOS will provide the initiative in standardizing the hydrographic project instructions. These instructions should be more comprehensive and better organized than previous NOS project instructions or NAVOCEANO hydrographic survey specifications. This working

group may have initiated the impetus towards a joint publication of the next edition of the Hydrographic Manual.

THE NEW HYDROGRAPHIC PROJECT INSTRUCTIONS

The first tangible result of the working group's activity is a reformatted version of the hydrographic project instructions. Prior to the meeting of the working group, NAVOCEANO had reviewed the NOS project instructions and determined them to be generally acceptable for their usage. During the meeting the instructions were examined item by item for relevance to the needs of each agency. The instructions were also examined as a whole to ensure that the organization was logical and that the sections were placed in the same order that the field work would be addressed. It was recognized that certain requirements unique to only one agency were of sufficient importance to that agency to merit inclusion within the instructions.

Rather than examine the instructions in detail, a general overview will be provided here. The instructions have been designed in an outline format. This permits considerable flexibility in the language within a given section. All previous instructions' formats consisted of from seven to nine topical sections. The new hydrographic project instructions consist of 10 major topics: general, participation, geodesy, topography, tides/water levels, hydrography, bottom investigations, ancillary tasks, reports, and miscellaneous. Previously, the topics were divided into sections which were not structured and could vary considerably from one set of instructions to the next. Within the topical headings of the new instructions is a specified structure of sections which remain unchanged in all instructions. If any section within this format is not applicable to a given hydrographic project, it is so annotated; but the numbered sections remain unchanged. The value of this policy is consistency among all instructions. The corresponding sections of all instructions will contain the same material. This simplifies the hydrographer's task by making it easier to locate any specific segment of the instructions.

The instructions are still flexible at the subsection level. By breaking the section topics into specific subsectional paragraphs, information unique to the given project can be given. These subsections may change from project to project, or even be omitted completely, however, to permit versatility.

As previously described, certain sections of the instructions such as vertical control and side scan sonar were inserted to respond to unique needs of only one of the involved agencies. Some sections which initially were considered to be pertinent to only one agency, however, have also been used advantageously by the other, such as security classification. Although obviously keyed to classifying surveys as related to national security for NAVOCEANO's purposes, the section is now used by NOS to remind Commanding Officers to use discretion in revealing the location of salvageable material to private concerns and also to annotate with an appropriate disclaimer any preliminary survey data released.

Two new areas of the hydrographic project instructions which merit mention are the wire drag section and the support data section. The recent emphasis on item investigations has made it necessary to define more precisely what is necessary to disprove the existence of a charted item. Since the only manner in which the presence of an obstruction can be disproved is by diver investigation or a wire drag (or similar technique), guidance on the requirements of an approved investigation by wire-drag techniques is detailed in the wire drag section. It refers to the pertinent portions of the Wire Drag Manual (Ulm 1959). The support data section defines those products that are made available to the field units by Headquarters. In it are outlined the services to be provided, the area providing each service, any required action on the part of the field unit, the anticipated time element, and the receiving area. This section should clarify those services available and how to trace them if not provided within the specified time.

No discussion of project instructions would be complete without mentioning the most controversial, yet most variable, aspect of their content. Their wordiness and detail are a direct reflection of the philosophy of the individual(s) writing those instructions and the policy of the originating office. There are those who would prefer nothing more from the project instructions than a description of the physical limits of the survey area and the time frame within which the survey is to be conducted. On the other hand, some Commanding Officers would apparently prefer that the instructions be so complete as to remind the Plotting Officer to check the paper tape supply. The present policy of the Requirements Branch of the Hydrographic Surveys Division is, hopefully, somewhere between these two extremes. The instructions should provide sufficient guidance to ensure that all the major portions of a properly conducted survey are listed with appropriate references to the Hydrographic Manual, fourth edition. There is absolutely no intent to infer that reading and understanding the manual is not a necessity. It is rather intended to prod the memories of those familiar with the manual and to direct those lacking familiarity to appropriate starting points.

SUMMARY

Hydrographic project instructions have a long history within NOS. Copies existing in the files date back to 1921. Through the years, the project instructions have evolved as the technology changed in hydrography. Early in 1979, NOS and NAVOCEANO met to discuss the ramifications of standardizing hydrographic project instructions to expedite cooperative efforts in times of national emergency. The resulting hydrographic project instructions should be the logical culmination of many years of development and experience in the hydrographic agencies.

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DISCUSSION

Mr. Barnes: You mentioned that photogrammetry has replaced the planetable, but the Hydrographic Manual does emphasize that planetable methods still do have a use.

Lt. Cdr. Suloff: Planetable techniques are still described in the manual, but they're not included in chapter 2 where it refers to the content of the project's instructions. They are not commonly used in the modern survey.

PRACTICAL APPLICATIONS OF PHOTOBATHYMETRY

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ABSTRACT. Photobathymetry, a method of measuring water depths, is a practical way to determine the configuration of the ocean floor by using aerial photography. The Photogrammetry Division is using a new, semiautomated system to assist in the acquisition and processing of photobathymetric information. The details and benefits of this new approach and other pertinent techniques used in photobathymetry are discussed.

INTRODUCTION

Because of increasing pressure for accurate up-to-date chart information by commercial and private users, improving the methods of acquiring and processing such information has a high priority within the National Ocean Survey (NOS).

Photobathymetry, the science of measuring water depths to determine bottom topography using aerial photography, has been introduced in recent years as an alternative tool for acquiring inshore bathymetric data in shallow waters. The use of photobathymetry can provide additional resource data to support the nautical charting and hydrographic operation at NOS.

The Photogrammetry Division performs photogrammetric shoreline mapping surveys to support the nautical charting program at NOS. These surveys provide new information concerning the characteristic of the shoreline, existing and possible hazards to navigation, and navigation aids. Through the application of photobathymetry during photogrammetric mapping operations, when applicable, inshore bathymetric data can be obtained and furnished in conjunction with other data. Information obtained by these surveys is used for chart maintenance and assisting in hydrographic surveys.

In St. Croix, Virgin Islands, mapping operations of a shoreline/photobathymetric survey are presently underway by the Photogrammetric Branch in the Office of Marine Surveys and Maps. A new system assists in collecting and processing bathymetric data in this region. This system, consisting of a stereoplotter interfaced with a digitizing unit and a series of computer programs, has greatly improved the efficiency of the photobathymetry mapping process.

The details of the photobathymetry mapping process and other related information, through a discussion of the St. Croix job, will be explained in this paper. The objective of this discussion is to provide the potential users of photobathymetric data with a general understanding of the process necessary to acquire such data.

PROCESSING PHOTOBATHYMETRIC DATA

Photobathymetric data consist of depth curves and discrete soundings and are compiled in conjunction with typical shoreline data. At present, photobathymetric data are compiled through the use of a Wild B-8S Stereoplotter interfaced with an ALTEX AC74A Digitizing Unit and Tape Transport. Stereo models are set in a conventional manner. Vertical and horizontal control points are used to level and scale the model to ensure the vertical and horizontal requirements, as established in the planning phase. The control points are used to orient the base manuscript to the model. Depth curves are compiled manually using logical underwater contouring methods. Soundings are digitally recorded as raw data and then processed using computer programs. Computer programs perform the following tasks: convert model (table) coordinates to actual ground positions; sort and merge data; make necessary vertical adjustments due to water refraction, earth curvature, and tide stages; generate plotting tapes; and other miscellaneous functions.

After shoreline compilation is accomplished, the raw photobathymetric data are compiled on tape via the digitizer. These raw data are in table coordinates and consist of X, Y, Z, event number, and a tide zone number for each sounding. At the end of model compilation, closing readings are taken of the fiducials and compared to the opening readings to assure that any potential electrical disturbance has not affected the point coordinates.

The raw photobathymetric data tape is sent to the Suitland Computer Center and combined with card data to establish a library tape. The process to the point of establishing a library tape is called "Phase 1." The results of Phase 1 are the library tape and a listing of the library tape data. This listing is reviewed to ensure that all data are in the proper format, control point information is correct, and that no gaps exist.

A plotter tape is then submitted to the computer center with card data specifying sheet limits, scale, and which library tapes are to be merged to form the photobathymetric data overlay. This stage of processing is referred to as "Phase 2" and is repeated twice. The results of Phase 2 are a plotter tape and listing printout.

The first plotter tape is then submitted to be run on the Marine Chart Division (MCD) Calcomp 718 or 748 flatbed plotters to generate an inked stable base positive. This positive plot is then reviewed for completeness and the depth curves are drawn on this base from the original work sheet. It is at this stage that an edit is done to compare the depth curves and discrete soundings. Due to congestion or duplication, certain discrete soundings may be deleted when a second Phase 2 is produced.

The plot tape from the second Phase 2 is submitted to MCD's plotter facility for a new plot. This plot is a scribecoat negative. From this negative, clear overlays are produced later.

After reviewing the various ways of displaying the photobathymetric data it was decided that the best way to present this data would be in overlay form. This would allow the base manuscript to show the classic items unique to shoreline compilation and not conflict with the density of soundings and depth curves. When merging the base manuscript with the bathymetric overlay, some soundings may again be deleted, only on the negative not the plot tape, due to conflicting data. The plotter tapes are stored for possible use in the MCD data bank. Unfortunately, the Phase 1 raw data cannot be saved due to the limited number of tapes in our library.

The depth curves are not part of the data on the plotter tape but are engraved on the scribecoat generated after the second Phase 2. Without the same use of photographic and stereoscopic methods, relief can be recognized only by indirect means and many questions as to details of topography and other features cannot be answered satisfactorily. To explore this problem various tests have been made in an attempt to compare the depth curves generated by the Contour Interpolation Program (CIP) used by the MCD and the curves compiled photogrammetrically. We believe that the CIP would be beneficial in areas where the relief is of a uniform slope. There are, of course, small isolated areas where the CIP could not possibly capture the true nature of the ocean floor. It is hoped, however, that this division will continue to furnish depth curves as requested by users and show them in the manner currently in use.

The Division's current photobathymetry system is very efficient, but we do have some problems and limitations. As mentioned before, we cannot retain Phase 1 raw data due primarily to a very small tape library. This problem could be solved by transferring raw data to cassettes or disk files.

Another problem is lack of trained personnel. We are constantly testing people to see who would be best suited for this type work. Although most of the people in this Division can see stereoscopically, not all are trained in topography. As a result we have started a small-scale training program to supply the number of personnel needed to meet the future demand for photobathymetry data.

At present, we have one duty station set up for photobathymetric data acquisition. In the future, we expect to have another station ready for compilation. This Division also has a new analytic stereoplotter which is connected with a PDP-11/45 computer--the National Ocean Survey Analytic Plotter (NOSAP). Besides the computer, it has tape, printing, and card units as well as its own plotting table. It is hoped that this new system will greatly streamline the photobathymetric data acquisition process and with work files and disk files available through the system, data storage will be much more efficient than the present system.

The benefits of a photobathymetric compilation of an area before a hydrographic survey are many. The cost of compiling the inshore areas would be reduced. Consider the number of personnel and craft that could be used elsewhere and the time involved surveying areas that can be surveyed through photobathymetry. Safety of personnel and equipment would be greater since during the photobathymetric compilation the least depths of shoals and shallow areas are delineated.

The amount of data could vary from area to area depending on the requirements of the users. At present, we are accumulating data in a 6- by 6-mm systematic pattern. It was determined that this pattern best assimilated the boat sheets. We are not restricted to that pattern, however, and can furnish greater densities of data if necessary. An example of this is the special map prepared at a scale of 1:5,000 for the Frederiksted Pier area of St. Croix. The density of data was increased by two times to meet the requirements for a future inset of this area, where once outside the limits of the future inset the original density of data was resumed.

As an example of the amount of data potentially available, let us look at the St. Croix shoreline/photobathymetric job currently underway. Of the nine manuscripts needed to cover the island, four have been completed in both the shoreline and photobathymetric compilation phases. The number of bathymetric points per manuscript varies from 500 to 6,000. Of the remaining five base manuscripts to be completed, it is estimated that two should contain approximately 1,500 points each, two approximately 6,000 points, with the remaining manuscript containing approximately 2,500 photobathymetric points. The special map prepared for the Frederiksted Pier contained 954 points. As a result, the potential data base of photobathymetric points amounts to approximately 27,000. This amount of data should help the future hydrographic survey operation scheduled for this area.

To meet the needs of future photobathymetric data users, we would like to form a working committee of production level people. This committee, restricted to the subject of photobathymetry and the needs of potential users, would consider the needs of all parties and could resolve any special problems. Through this process the overall system could be streamlined and any unnecessary operation could be deleted.

The Photogrammetry Division believes that photobathymetry is a step towards furnishing valuable data for the use of our counterparts in NOS and a great aid in helping NOS strive towards the goal of providing the most current, accurate data for use of the public and private sectors of maritime society.

DISCUSSION

Lt. Cdr. Lapine: I have two questions. You mentioned that some of your models are offshore models. How do you pick pass points in an offshore model?

Mr. Fromm: On this project, the initial requirement--I want to relate to this project--was to go out to the depth of 18-feet, so we had a general

idea of the offshore distance of the control needed. The image points were picked and read in aerotriangulation and positioned so, but depths are apparent. We also had men in boats taking random soundings. These boats were identifiable on low altitude photography, and we then transferred this information to our compilation photography so we could actually key in on the true depth.

Lt. Cdr. Lapine: You knew the position of the boat, therefore, you used that as a pass point?

Mr. Fromm: No. The approximate position of the boat is known. It is very close, but not absolute.

Lt. Cdr. Lapine: The other question I had was how do you handle the refraction of light as it passes between the air and the water medium?

Mr. Fromm: This has been the subject for many papers by this division in the past. What we have generated are depth correction factors. The correction increases the farther you get towards the outside of the model. We simply multiply the correction factors by the apparent depth reading.

Lt. Cdr. Suloff: How it's handled in the program--I think that's what he wants to know.

Mr. Fromm: Graphic routines used in the past have been replaced by computer software.

Lt. Mason: You have the analytical plotter there and then you have the B-8 stereoplotter digitized. Does this imply that photogrammetry now has a standard digital format by which they can transfer digital data from one system to another and to outside users?

Mr. Fromm: I was afraid I might be asked that. No. At the outset of my introduction, I made reference to this as our first venture into the use of computer software. What we have come up with in the digitizing unit, and the B-8 is a system which simply eliminates human judgment in determining true depths and positioning of those true depths. In the future we will be very concerned about this. We do have the NOSAP with the PDP-11/45. We will use this and the B-8's, and we should be using the same software.

Lt. Mason: That is an objective in the very near future?

Mr. Fromm: Yes

Lt. Mason: Yes. Good.

Mr. Rodkey: I might add that the present format of our plotter tapes is supposed to be compatible with the marine charts data bank. No test has really been done, to this point. We are keeping the plotter tapes right now because that's our end product. That is, all the corrections have been made to that point. And so these are in reserve now. The conversion into the PDP-11/45 system is underway, but its completion is a fair distance down the road.

Lt. Mason: Thank you.

Lt. Cdr. Bass: I notice you're collecting both depths and curves. Are you retaining the curves on your tapes, or are you just discarding them after you make your plots?

Mr. Fromm: No, at the present time we have no way of direct access to using contouring methods on the instrument and putting them on tape. I don't know in the future whether this would be feasible or not. Whenever you deal with the art of hypsography, in this case submarine, you must make adjustments. You cannot come directly off the instrument with a contour. You must shape the contours to show the true configuration of the bottom.

Cdr. Simmons: Greg, one goal of the NOSAP system or one capability of the NOSAP system, once it is completely programmed, will be the capability to draw underwater contours, making real time corrections for the refraction, and in that case we would be able to store contours on tape. That's not possible right now because the software is not complete, but that's one thing that's being worked on.

Mr. Fromm: We will need the capability to edit on line. That will be the key.

Cdr. Nortrup: I missed about three questions here. First of all, in your St. Croix project, were you able to control the photography without resort to underwater control points and subsurface targeting?

Mr. Fromm: No. Well, we utilized both in compilation. The original instructions were only to 18 feet, which was a relatively short distance from the shoreline. In viewing our display over here, you will see that we went to depths of 40 or 45 feet. The reason for this was to try to use, or come up with, systematic patterns so we could attempt to use the contour interpolation program used by the Marine Chart Division.

Cdr. Nortrup: What was the nature of your subsurface control points?

Mr. Fromm: Horizontal or vertical?

Cdr. Nortrup: Horizontal.

Mr. Fromm: Horizontal control was determined through aerotriangulation.

Cdr. Nortrup: Are you actually saying, when you've got depths out to 45 feet, that's what your maximum depth capability was? Is there any plan for a field verification after you've compiled this area?

Mr. Fromm: Photobathymetry, like any science, is not absolute. Depending on the requirements, we believe, through practical application, that we can provide accurate data. Due to changes in the bottom, etc., a field verification may be impossible when attempting to zero in on the exact horizontal positioning of a sounding. You can work in generalities of an area. I believe that the hydrographer, in using our data and merging the two, will find that possibly a slight vertical adjustment could be made to all of our data, if deemed necessary.

Mr. Perrow: To answer your question somewhat, Don, there will be a hydrosurvey done in this area in the near future. That's one reason we went out a little further than what we had been asked to do, hoping that the overlap would give some ground truth to what we had been doing in the office.

Cdr. Richards: In the process that you go through in picking 6-mm spacing per sounding, is there a review process where someone goes back and says, we see a shoal developing, but the 6-mm sampling perhaps didn't get the least depth in an area, and then you come back and get another sampling in that area?

Mr. Fromm: I believe we have instituted a safeguard in this, or a margin of safety in this respect. The 6- by 6-mm spacing is displayed at map scale. We actually accumulate data at four times that density, so this does give us an added capability. We are assured that we are given the least depths. We also then scan the model by conventional methods to assure that the least depths in shallow areas are provided.

Mr. Rodkey: I'd like to expand on that further. After the soundings are taken along the sounding line, the compiler goes back over the model and investigates the questionable areas. Anything that you don't think would be picked up by what you've already done is collected. If there is duplication in the final plot where numbers are overprinting each other, then we make sure that the shallowest depth is shown.

Lt. Anderson: Do you have any trouble with sea swells and waves changing the refraction?

Mr. Fromm: If we can see the bottom, no. Photobathymetry is limited. This is due to photo resolution, wave action, sun spots, bottom sediment, etc. We don't have any trouble with refraction. I believe this is a built-in safeguard, with regard to the stage of tide that we use in our program.

Lt. Cdr. Lapine: In the future, would you have offshore, underwater, horizontal control points, targeted offshore points?

Mr. Fromm: This is a possibility. Maybe I should have our division chief expand on that further.

Mr. Perrow: The accuracy for the horizontal is not really needed, to that extent. We can provide a horizontal accuracy of positions underwater, which we can see, completely compatible with anything that the hydrosurvey is going to put there right now. There is no real need for a permanent horizontal positioning there, as long as we can hook these models to land, and base it on the triangulation on the land, horizontally.

Lt. Cdr. Floyd: I've had a problem here in how you connect your offshore photobathymetry to the shoreline. You don't have any control out there. You mentioned something about a boat, but I didn't understand what you were talking about.

Mr. Fromm: When I was referring to a boat, that was totally for vertical accuracy. For horizontal positioning, we set a stereo model. Control is a series of pass points picked at random--six points--in our aerotriangulation section. This provides us with adequate horizontal control, two of which are in the offshore direction. We would never exceed the offshore distance of those pass points to compile any data.

Mr. Rodkey: I'll expand on that a little more. The vertical control needed offshore was done in a method where someone was out in a small boat and a plane flew over taking low altitude photography, strictly with the idea of taking a picture of that boat, in comparison to configuration of the bottom. When the plane flew over, the person read the depth of the water. That was adjusted for tide and used in the aerotriangulation fit, the strip adjustment, to give us vertical control offshore. The offshore models are tied to the land models by tie points. A series of tie points are selected and each strip is tied to the other one and an overall block adjustment is computed. All the points are evaluated at that time. You always end up with very good horizontal control. The triangulation stations are third order stations, and you have true and accurate depths offshore, based on tide and time.

Cdr. Richards: How do you pick your tie points?

Mr. Rodkey: The tie points are just picked arbitrarily in triangulation. They can be an image figure. They view it stereoscopically to assure that these points will be identifiable in the next strip.

Mr. Fromm: If I may interrupt, if you'd like to see us on break, I believe we can show you, or discuss this further, as to how we actually control our photography.

Mr. Rodkey: If anybody has any questions after this, or really doesn't understand photobathymetry, or photogrammetry for that matter, we're in Building 2, stop by. See Mr. Perrow, and he'll bring you around.

GREAT LAKES PHOTOGRAMMETRIC ACTIVITY

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ABSTRACT. Photogrammetric mapping is relatively new to the Great Lakes compared with previous National Ocean Survey activities. This paper presents the photogrammetric activities completed, in operation, and proposed for the Great Lakes area, highlighting hydrographic projects. Also discussed are the importance of Great Lakes mapping and some of the problems with satisfying the needs of hydrographic surveys.

INTRODUCTION

Most people do not realize the volume of work needed to maintain the charting activity on the Great Lakes. The U.S. shores of the Great Lakes have a total of 5,500 miles of shoreline--twice the distance from the tip of Florida to the northernmost shoreline of Maine. The Great Lakes have one of the largest registrations of recreational boating of any area in the world, as treacherous seas as the oceans, areas of flooding comparable to areas destroyed by hurricanes, a tremendous volume of shipping tonnage--1/8 of the total U.S. shipping, some of the largest seaports in the world, and they make up the largest body of fresh water on the entire continent (95,000 square miles).

In September 1979, a Coastal Mapping Workshop held in Ann Arbor, Mich., was comparable to others held at various locations around the country. It was the best workshop of any to date with the greatest participation concerning State programs. Shoreline erosion studies, flood zone mapping, pollution studies, and hydrographic studies, to name just a few, indicate the importance of the area.

I have not prepared a highly technical paper but would like to take a few minutes to show the photogrammetric projects that have been completed, the projects in operation now, and the work planned for the area of the Great Lakes.

WORK COMPLETED

Many photogrammetric projects have been completed on the Great Lakes. The original plan was to recompile all the harbors and connecting waterways using analytical aerotriangulation where adequate horizontal control was

available. A photo revision update on the shorelines of the navigational charts, one lake at a time starting with Lake Superior, would suffice for the remaining areas.

Duluth-Superior Harbor, at 1:15,000 scale with the inset of the upper St. Louis River at 1:30,000, was compiled for an aid in hydrographic compilation and was registered as a Class I map. Lake Superior shoreline was revised and all harbor insets on the navigational charts were compiled by stereoplotter methods.

On Lake Michigan, Milwaukee and Baileys Harbors were compiled and registered as Class I maps at a scale of 1:10,000. A hydrographic survey was performed in the Baileys Harbor area since no previous harbor chart existed. The other harbor charts compiled were Marionette-Menominee, Burns, Holland, and Muskegon Harbor, all at 1:15,000 scale.

Three projects connected with Lake Huron were completed. The largest, for the St. Clair River and Port Huron, originated as a hydrographic project and was compiled at 1:6,000 scale because the Kelsh stereoplotter necessitated an enlargement of 5X from 1:30,000-scale photography. The hydrographic work was subsequently compiled with the stereoplotter. Au Gres Harbor is newly constructed and had not been previously mapped.

A considerable amount of mapping activity has been performed on Lake Erie, partly because of its close proximity to Detroit and the Detroit River. The major project completed was the entire south shore from Vermilion, Ohio, to Fairport, Ohio. Eleven 1:10,000-scale topographic photogrammetry (TP) sheets, one 1:20,000 scale, and four 1:5,000 scale maps were registered as Class III maps. Other projects included Toledo Harbor at 1:20,000 scale, Huron and Ashtabula Harbors at 1:5,000 scale, and Erie and Buffalo Harbors at 1:15,000 scale. Buffalo Harbor was supplied at 1:10,000 for shoreline on the hydrographic project, also.

WORK IN OPERATION

Some photogrammetric projects in operation have not been completed yet. Ashland and Marquette Harbors are being compiled at 1:15,000 scale; Keweenaw Waterway and Keweenaw Bay are being compiled at 1:10,000 scale. The St. Marys River is scheduled for 1:20,000-scale compilation. On Lake Michigan, Green Bay and Fox River are being worked at 1:15,000 scale, while the Chicago waterfront and Calumet Lake and Calumet River are compiled at 1:10,000 scale. In addition, there are nine small harbor projects on Lake Michigan to be completed. The only two projects in operation on Lake Erie are the four TP maps on the Detroit River at 1:15,000 scale and Sandusky Harbor at 1:10,000 scale.

WORK PLANNED

Many photogrammetric projects are planned or being planned for the next 2 years. On Lake Superior, seven TP maps at a scale of 1:10,000 are scheduled for the Apostle Islands bordering the shipping lanes in the western part of the islands. On Lake Huron, Bay City, Saginaw, and Saginaw River are planned for 1:20,000-scale compilation. The south shore of Lake Ontario from Oswego to Niagara River and the east end of Lake Ontario are scheduled for 1:20,000-scale TP sheet compilations. Sodus Bay, Oswego, and Rochester Harbors on Lake Ontario are planned also at a scale of 1:10,000. All Lake Ontario manuscripts are to be used for shoreline depiction on hydrographic surveys.

Nine TP maps are planned for the St. Lawrence River at 1:25,000 scale. Onieda Lake and Lake Champlain will be compiled at 1:40,000 scale.

COMMENTS

All Great Lakes projects have been and are being compiled at chart scale by direction from the Marine Chart Division in the Office of Marine Surveys and Maps. It is good to see more of this type of planning by the Hydrographic Branch. Maps larger than chart scale take a lot more work and time setting stereo models and compiling.

Revision work, an important procedure for supplying shoreline data for hydrographic surveys is accomplished in part with NANCI facilities in Reston, Va., with our National Ocean Survey (NOS) personnel.

Advance notice for proposed hydrographic projects such as the south shore of Lake Ontario will help in the planning of photogrammetric projects. An example of a project that could have been handled more efficiently is the recent Buffalo Harbor project. After the harbor chart was completed a subsequent request was made for the Niagara River. Had this been requested sooner, photography could have been extended to cover the river as well as Buffalo Harbor.

One of the biggest problems on the Great Lakes work has been the lack of adequate horizontal control in many areas. The former Lake Survey horizontal control has still not been incorporated into the National Geodetic Survey (NGS) system. This would at least be an aid for control where nothing else exists. NGS is working on the Lake Superior and St. Marys River horizontal control problem. The reconnaissance work has been completed and the densification of horizontal control is expected to be completed by 1984.

A general reluctance on the part of field people to go to the Great Lakes area curtails the control work needed to position our photography and the field editing of the completed Class III maps.

A shortage of field personnel available for setting hydro signals for hydrographic work has hindered some projects such as the Apostle Islands.

More calendar field time is available on the Lakes than has been used with equipment and personnel for whatever reason.

Previously, chart compilations had been requested at 1:10,000 or larger scale when 1:20,000 chart scale would have been perfectly adequate, since the coastline authority is the photogrammetric TP sheets. Consequently a 2X enlargement from the photogrammetric base would be adequate for the survey.

In conclusion, I would like to say that every effort is being made to bring the Great Lakes charts to greater accuracy by photogrammetric methods, particularly the larger scale harbor charts. These newly compiled charts with horizontal control improvement will be of increased value for hydrographic surveys.

DISCUSSION

Lt. Cdr. Bass: It looks like you have a lot of TP sheet work out there. Are there plans to put this in a digital form or to compile it in a digital form?

Mr. Watts: All TP sheets eventually will be digitized, yes, but I don't know when that will be. Usually the TP sheets are digitized after the charts have been compiled by the cartographic units and not by the photogrammetric units.

Lt. Cdr. Lapine: I'd just like to comment about the horizontal control problem. It's not so much that the control does not exist. The problem is that it was never archived properly in the first place.

Mr. Watts: I realize that.

Lt. Cdr. Lapine: On the St. Mary's River, recently, we uncovered 600 control stations that were never even submitted into any sort of archive. Now we have cahiers upon cahiers of information neither properly recorded nor formatted, so it's going to be a while.

Mr. Watts: Am I correct that some 30-meter error in horizontal positioning was discovered up there. Is this new additional control expected to solve that positioning problem?

Lt. Cdr. Lapine: The problem is that all the survey work was originally done on the Great Lakes datum, which was never strongly tied into NAD-1927. What we are attempting to do now is make that tie, and then readjust all the Great Lakes datum information.

Mr. Watts: Thank you.

Cdr. Richards: What datum is that compilation that you showed based upon? Is it based upon the 1902 or 1927?

Mr. Watts: 1927 datum, yes, sir. All of our work now will be based upon the 1927 datum. Thank you very much.

PHOTOGRAMMETRIC LOCATION OF HYDROGRAPHIC SIGNAL SITES

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ABSTRACT. When visual fixes were used to position hydrographic surveys, the hydrographic signal sites were often positioned by graphic methods using specially prepared hydrographic support photography. With the introduction of the precise positioning, short range systems for hydrography, horizontal specifications for locating the sites became third order or better. The earlier method of graphically locating hydrographic signal sites does not meet these criteria. By using specific photogrammetric methods, however, the positions for electronic signal sites can be positioned accurately enough to meet the needs of the hydrographer and to stay within the tolerances needed. The result of using photogrammetric methods along with, or in lieu of, ground survey methods will increase the amount of hydrographic support data and save time in establishing the control.

At the Hydrographic Conference held in 1978, the Chief, Coastal Mapping Division, and the Chief, Surveys Planning Branch, of NOS headquarters led a round-table discussion on "Coastal Mapping Support for Hydrographic Surveys." Four of the subjects discussed were:

(1) The proper use of photogrammetrically determined points for controlling hydrographic surveys.

(2) The use of photogrammetric techniques to locate electronic control stations vs. standard surveying procedures.

(3) The advisability of premarking aids to navigation vs. location by surveying techniques.

(4) The increased use of photo-identifiable objects vs. paneled points.

In 1979, the Chief, Hydrographic Surveys Branch, of the NOS Atlantic Marine Center (AMC), led a discussion on "Should Accuracy Standards Be Based on the Scale of the Survey?" The discussion focused on using photo-picked points for electronic control and the relationship of survey scale and accuracy requirements.

We have lost 2 years since these ideas were first presented. Those were valuable years during which we could have been using a very productive technique to achieve our purpose of giving the taxpayer the highest quality data for the least amount of expenditure. The ideas themselves were not new, but were applications that have been used for years. They have been refined as our photogrammetric knowledge has increased. The accuracies achieved by photogrammetric methods have been proven in many cases with respect to volume and area. Its use as a water depth measuring device was proven in several photobathymetric projects most notably in the Virgin Islands. Recently its accuracy in horizontal positioning has been proven by a National Ocean Survey project in Ada County, Idaho, where second-order horizontal accuracies were attained.

Certain considerations must be taken when using photogrammetrically determined points for the horizontal control of hydrographic surveys. Most important is: "Can accuracy requirements be met?" It is conclusive that given the proper procedures they can. If in different circumstances they cannot be met, we should reevaluate and possibly relax the specifications so that more efficient methods that are adequate can be used. The Hydrographic Manual (Umbach 1976) states in Section 1.3.1:

> Third-order Class I accuracy is generally the minimum acceptable criteria for the location of electronic positioning system antenna sites and calibration signals, theodolite intersection instruments (cutoff) stations, and supplemental control schemes from which hydrographic signals will be located by conventional survey methods . . .
>
> Hydrographic signals for sextant-controlled hydrography may be located by sextant fixes or by sextant cuts. Less than third-order traverse methods may be used if the distance from a basic or supplemental control station does not exceed 4 km for hydrographic surveys at scales of 1:10,000 or smaller or 2 km for larger scale surveys.
>
> Photogrammetric methods may be used to position hydrographic stations for visually controlled surveys (photo-hydro stations) if these two conditions are met:
>
> The compilation scale of the shoreline manuscript is larger than or equal to the hydrographic survey sheet.
>
> The photo-hydro support data have been prepared and provided to the field party.

> Electronic positioning system antenna sites and calibration stations may be located photogrammetrically, provided that the stations have been marked with targets prior to aerial photography, the positions have been determined by analytic aerotriangulation, and the method is approved in the project instructions.

Captain Umbach, when writing these specifications, was aware that by following certain procedures, horizontal control located by analytic aerotriangulation methods would satisfy the accuracy needed for electronic signal sites (ESS). Accuracy has many definitions depending on who is being asked and in what context the question is asked. Accuracy in the general statistical sense denotes the closeness of computations or estimates to the exact or true values. Precision is a quality associated with a class of measurements and refers to the way in which repeated observations conform to themselves. By using 1:30,000 scale photography in the aerotriangulation process, a repeated accuracy of 5 feet is achieved horizontally. Obviously, this 5-foot repeatability will not satisfy third-order specifications within a small area, but it will meet them if the area is large enough. To increase this accuracy, the flying height must be lowered and more photos taken to cover an equivalent area; but, in many instances, this is justified.

Rather than reiterate the points discussed in 1978 and 1979, I will describe a scenario for an imaginary project to show its practical application. The project is an ideal one where it would be cost and time effective to use photogrammetric methods in lieu of ground survey methods to locate the ESS. There is a great amount of cultural detail, with an unlimited number of photo-identifiable points within 100 meters of the shoreline that can be used as signal sites. It would require an excessive amount of time and effort to position the signal sites to third-order Class I standards using standard surveying methods.

The Photogrammetry Division has received its copy of the hydrographic instructions through the Requirements Branch specifying that the ESS and calibration stations should be positioned by aerotriangulation methods. The Photogrammetry Division determines the physical limits of the project, sets the scale (normally two times the scale of the hydrographic survey) of the sheets, and specifies the flying height so that the required accuracy can be attained. The location and quantity of control stations to be identified for aerotriangulation are determined--usually four or more stations per flight line. There are two methods for locating this control. The one specified in the Hydro Manual requires the premarking of control points prior to photography. The other, which I prefer, establishes positions on photo-identified control points. A set of field instructions is written for the survey team specifying which control is to be identified along with alternate substitute control for specified stations found destroyed in the field.

The field party will have one person aboard who is familiar with the requirements for ESS, i.e., intervisibility with work area, not overly elevated, etc. When the horizontal control is photo-identified, ground surveyed positions will be established on photo-identified points that will be positioned later by photogrammetric methods; the launch will use at least

two or more (depending on the area covered) of these points for calibration during the hydro work. After the ground survey work is finished, the party will visit suitable ESS within the working area, prick the sites on a photograph, and make a detailed sketch to define the point well enough so that there is little or no chance of the point being misidentified in the bridging process or later by the hydrographer when he or she sets the equipment on it. At least 50 percent more points will be pricked and identified than would normally be needed to reduce chances of an error causing a hiatus in the control. After the field survey work is completed, the data (photos and sketches included) are returned to Rockville for analytical stereo-bridging. The Class III maps are then compiled and a copy is given to the hydrographer. On the Class III sheet all of the stereo-bridge positions of the photo-identified signal sites are also furnished to the hydrographer for use as input and check data. After the hydrographic work is completed, the hydrographer deletes from the manuscript those positions not used for control and writes a detailed analysis of the adequacy of the control and what procedures should be changed, improved, etc.

In reality, this scenario is somewhat after the fact. We at the Atlantic Marine Center have had open discussions between the Hydrographic Surveys Branch and the Photogrammetric Branch on doing a project similar to the one detailed above. Unfortunately, the first project we were to test did not materialize, but we are in the process of choosing a project that can follow the sequence with slight variations. In the meantime, we are starting a partial test project on the West Coast, CM-7711, Shilshole Bay to Sand Point. The control has been bridged; the sheets have been compiled and field edited. However, the Pacific Marine Center intends to use the sheets for training purposes and is doing additional field edit. If time allows before the field training starts, we will reset the bridging photography on our digitized stereo-plotter and establish positions on points that possibly could be used to set up electronic signals. The field crew will use these points along with ground survey points to determine the adequacy of the method. Alternately, at the same time as the field crew locates by ground survey methods points for electronic signal sites, they will precisely identify them by pricking them on a ratio print and drawing a dimensioned sketch of the point located. We will set the bridging photos in the digitized stereo-plotter, drop these points, and make a comparison in the office between the surveyed and the digitized position both from the digitizing table using the compiled manuscript and the digitized stereo-plotter using the bridging photography. The results of these tests will be available upon request.

Considering the many possibilities for inaccuracies occurring in the exact positioning of soundings, I can understand why the hydrographer would desire a high order of surveying to position the electronic signal sites. We must ask ourselves, however, are we putting too many restraints on a viable source that can provide sufficiently accurate data to meet the hydrographer's needs in an efficient manner?

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DISCUSSION

Lt. Cdr. Suloff: I'm going to give everyone else a chance to say something before I comment.

Mr. Barnes: Be my guest. I'm on the firing line.

Lt. Cdr. Suloff: A couple of quick comments on what you've proposed and some present policy. First of all, on the proposal to relax the third order, Class I requirement for electronic control stations: It's interesting to note that as the state of technology evolves and we get perhaps--I should underline the word perhaps--higher accuracy equipment, we learn at the same time more about the physical factors which degrade the accuracy of that equipment--propagation values over fresh water, salt water, or mixtures of the two, air eclipses, etc. Even though our technology is increasing, we're learning that the accuracy probably was never as great as we thought it was, so we feel the need to hold on to what we have as far as the accuracies required. I do not believe that, at least at this time, we'd be willing to release that requirement. One requirement we have imposed on the field units, using photogrammetrically picked points located by aerotriangulation methods, is that they verify the positions to the degree that they run electronic inverses to compare to the calculated inverses between intervisible positions. This at least verifies the relationship between the two as being correct in one dimension.

About requesting data, all requests for surveys are initiated by the Marine Chart Division, since all of our surveys are in support of marine charting products. They are identified at present in a survey priorities list--a 5-year plan, if you will--that is the coordinated effort of representatives of the Marine Chart Division, the Hydrographic Surveys Division, and the Photogrammetric Division. We are in the latest version of that 5-year plan, identifying by priority photogrammetric and photobathymetry efforts, and we are identifying the product which is proposed by the Photogrammetric Division, whether it is shoreline revision, shoreline compilation, photo-hydrosupport, or aerotriangulation. Rather than my office attempting to identify for the field unit where they will need aerotriangulation, we are identifying by letter "A" and a question mark all projects which would lend themselves to aerotriangulation. We will leave it to the Marine Center, and specifically the field units, to make known to the Photogrammetry Division the desirability of that air triangulation and to help depict the points. The real weakness in all this is that the persons on the field unit right now are not the persons who are going to be there 2 and 3 years from now, who will make benefit of that service. (The user will not be the same as the identifier.) You will have to look out for the guy who follows you. I think that pretty well summarizes what we're trying to do right now.

Mr. Barnes: As I did some research for this, I talked to various hydrographers and various points were brought up about physically placing the Del Norte, Miniranger, and so on, on the traverse stations, and it became apparent why the base control should be so accurate. I won't elaborate further.

Any more questions? Yes, sir?

Cdr. Nortrup: As I recall, a couple of years ago, when trying to get just the capability for on-line digitization was a hot item, one of the objectives was to be able to provide the field unit with a digitized version of the T-sheet, compatible with the Hydroplot system.

Mr. Barnes: Exactly.

Cdr. Nortrup: What's the status of that?

Mr. Barnes: This is still, I would hope, Photogrammetry's desire. This is my desire: instead of a hydrographer taking his plot sheet, laying a T-sheet underneath, and physically tracing off at the same time, or prior to doing hydro, he would take a paper tape or mag tape, put it on the shipboard computer or whatever, and be able to produce a sounding sheet with the shoreline and the soundings on it simultaneously. This, to me, would be the ultimate.

Cdr. Nortrup: We've still got a ways to go, though, apparently.

Mr. Barnes: Incidentally, as a point of interest, Jack Ehrhardt who is developing the software and Helen Sharpe--he's from Processing, and Helen Sharpe is from the Photogrammetric Branch--this is tentative, but we hope to be able for these two people to go to the Pacific Marine Center at the time we get our system functional so that we're not duplicating effort, which has happened so many times in the past.

Any more questions? Yes, sir?

Cdr. Nortrup: One more observation. I'll back up a little further, on Don's comment about photogrammetric location of electronic control stations. I think maybe one other consideration ought to be factored into the deliberations on photo control for electronic control station location, and that being the idea of redundant electronic control stations, i.e., the location of three or four photolocated signals, the locations of electronic control stations, and the monitoring of the line's positions from each of three or four, which makes the whole net, in essence, a self-verifying net, and if that capability--I gather from discussions earlier this week, that the capability to handle redundant positioning rates is still pretty formative, but if that capability is made available, and the whole system can be made self-verifying, I personally see no reason why we could not go to even field photolocated signals, verified through redundancy.

Mr. Barnes: Lt. Cdr. Suloff.

Lt. Cdr. Suloff: This is, in fact, one of the prime objections to the photogrammetrically determined control station. When we're using photogrammetric purposes for visual control, we had that redundancy. At least three control signals were used for each position. Most of our electronic work is now range-range. There would be no check. So, I agree completely with Don. It would be desirable not only for photogrammetric control, but for all control to have redundant positions.

Mr. Barnes: Lt. Mason?

Lt. Mason: I hate to dump my own dirty laundry in front of this conference, but on what basis do you make the cost effectiveness statement of digitizing directly from the plates as opposed to digitizing from the T-sheets?

Mr. Barnes: The time involved in reviewing the product on the B-8 or in the stereo model as opposed to having a sheet that has been reviewed.

Lt. Mason: Is that something that can be improved by the computer people, or is that a wall--

Mr. Barnes: That is a compilation situation. Now, we have only the one stereo plotter interfaced; if we had three, the cost benefits would probably increase. We do have--I stand slightly corrected on this, maybe, but--an editing capability on line when we compile data on the B-8, using this system, if we have a section of shoreline. Let's say this shoreline's incorrect, and we want to delete the section. We not only delete this section of shoreline, we have an upper right and a lower left corner of an area from which the entire bit of information is being deleted. It can be readded if an error is found in the review process on the stereoplotter, which, eventually, should be improved. So that by cartocodes, from point to point, we should be able to do the edit work.

Mr. Perrow: Another question back here.

Mr. Barnes: Yes?

Lt. Cdr. Lapine: I don't mean to turn this into a discussion, but the redundancy of electronic navigation is not necessarily improvement to the accuracy, as Mr. Moore pointed out yesterday. The only square root of the number of stations is the percent of increased accuracy and then only dependant on the intersection between those various rates.

Mr. Barnes: Just as an aside, when the inertial survey system is purchased, Photogrammetry would like first chance at using it.

APPLICABILITY OF HISTORICAL INFORMATION TO THE CORRECTIONS OF ECHO SOUNDINGS*

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ABSTRACT. Current methods for determining sound speed corrections for echo soundings in continental shelf areas are time-consuming and expensive. A study of historical sound speed data for an east coast shelf area indicates that temporal and spatial variability exceeds acceptable limits for sounding corrections, thus precluding the use of only these data for determining correctors. Acceptable sound speed corrections can be made by using historical salinity values and in-situ temperature measurements from expendable bathythermograph probes. Salinity may be able to be determined from water temperatures alone, however, because of the constant relationship between temperature and salinity.

INTRODUCTION

All depths determined by echo sounder are based on an assumed speed of sound in seawater. Corrections must be applied to these depths to account for the difference between the assumed and actual speed of sound. Present practice dictates that in-situ measurement of the sound speed profile in a working area be made and depth corrections computed.

This study was made to determine if temporal and spatial sound speed variability in a continental shelf area is small enough to allow use of historical salinity and temperature data in the National Oceanographic Data Center's (NODC) oceanographic station file to correct echo soundings. Historical data within a sample coastal region were examined to determine if correctors of sufficient accuracy could be obtained without in-situ measurements. Applicability of historical data (in the form of temperature and salinity measurements) has been widely discussed, but limits of applicability have not been well documented (Mobley 1977).

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*Summary of "Coastal Controls on Vertical Sound Speed Determination and Corrections to Echo Soundings," unpublished Master's Thesis, U.S. Naval Postgraduate School, Monterey, Calif., 1979.

Echo sounders do not measure depth directly, but rather measure the time delay between an outgoing sound pulse and the return echo of this pulse. Depth is then derived by dividing the round trip travel time by two and multiplying this value by the assumed speed of sound in seawater. The depth displayed is the nominal or fathometer depth. True depth can be determined only if the sound speed profile through the water column is known and used to calculate depth as in the following equation (Greenberg and Sweers 1972):

$$Z = \frac{1}{2}\int_0^{2\Delta t} V(Z_t)dt \qquad (1)$$

"where $V(Z_t)$ is the sound speed at the level Z_t where the signal passes at the time $0<t<2\Delta t$, corrected depth is derived from nominal depth by applying a correction according to some standardized procedure."

The assumed speed of sound used in construction of echo sounders for hydrographic surveying is usually either 1,463 meters per second (800 fathoms per second) or 1,500 meters per second (820 fathoms per second). Echo sounders used by the National Ocean Survey (NOS) are calibrated with an assumed sound speed of 1,463 meters per second. This value is reasonably near the actual speeds encountered in most waters surveyed by NOS (Umbach 1976). Field measurements of sound speed are made during the course of a survey to determine representative vertical column sound speeds for a location (Umbach 1976). These field measurements and their reduction are often time consuming, expensive, and result in considerable conjecture about areas and times of corrector applicability.

ACCURACY REQUIREMENTS

The requirements for accuracy of echo soundings are based on standards agreed to by member states of the International Hydrographic Bureau (IHB). Depth measurement requirements are stated in Special Publication 44, "Accuracy Standards Recommended for Hydrographic Surveys" (International Hydrographic Bureau 1968). These standards vary with depth and are summarized in the Hydrographic Manual (Umbach 1976). They represent the maximum allowable errors in measurement of depth from all sources, including variation of sound speed in the water column.

NOS requirements for accuracy in determining the speed of sound for correcting echo soundings are stated as follows (Umbach 1976):

> The velocity of sound must be known with sufficient accuracy to ensure that no sounding will be in error by as much as 0.25% of the depth from this cause alone. Therefore, the mean velocity of sound must be known to within ± 4 meters per second.

These standards apply only to conventional echo sounding systems. An implicit assumption is that the sound pulse or beam is vertical. Future systems such as the Bathymetric Swath Sonar System (BS^3), will require greater

accuracies. The longer acoustic path lengths, as well as varying trajectories, make this technique more sensitive to sound speed errors. Accuracy requirements for such a system have been stated as ± 2 meters per second (Mobley 1977).

PREVIOUS USES OF HISTORICAL DATA

Several attempts have been made to use historical sound speed corrections. These have usually taken the form of historical tables or atlases of sound speeds or salinity and temperature data observed in the same area and season as the operations. Tables such as Matthews Tables (Matthews 1939) and Heck and Service's Tables (Heck and Service 1924) have been in use for quite some time with periodic efforts being made to improve upon the accuracy of the results (Ryan 1974). These tables have not been applied generally to depths of 200 meters or less (Sherwood 1974).

COMPUTATION OF SOUND SPEED

Various theoretical equations have been developed to relate sound speed to density and elasticity of the medium. It is standard practice within NOS, however, to use an empirical equation relating sound speed to salinity, temperature, and pressure. The equation, a form of Wilson's 1960 equation for speed of sound in seawater (Umbach 1976), was used to compute sound speeds for the NODC data as well. As stated in the <u>Hydrographic Manual</u>, using Wilson's equation, temperature measurement accuracies of ± 1°C and salinity measurement accuracies of ± 1 ppt are needed to satisfy sound speed correction requirements (Umbach 1976).

In 1976 the Testing Division, Office of Marine Technology (OMT), NOS, made an analysis of the Wilson equation to determine sensitivity of the equation to variations of temperature and salinity (Bivins 1976). Their results were stated as follows:

> If corrections were made on the basis of temperature measurements with a one sigma (1σ) accuracy of ±0.1°C, a natural variability of ± 3 ppt (1σ) from the measured salinity could be tolerated and the NOS sound speed accuracy of ± 4 meters per second would be satisfied.

This analysis pointed out that the most critical measurement was temperature, and if temperature accuracies of 0.1°C were met, then salinity measurement errors within a larger range than previously noted could be tolerated. The accuracy requirements, as well as the OMT analysis, all bear on the acceptability of using historical information to correct echo soundings.

PROCEDURE AND METHODS

To examine the temporal and spatial variability of sound speed, temperature, and salinity for a representative shelf area, a coastal region offshore of Charleston, S.C., was selected as a study area. The area extended from

latitude 32^{0}N to 33^{0}N and from longitude $78^{0}30'$W to 80^{0}W. This area (fig. 1) was chosen for several reasons:

First, it appeared representative of the oceanographic environments characteristic of east coast survey areas. Second, the size of the region was typical of a 1-year hydrographic project by a single coastal survey ship or a 6-month project by two ships. Third, examination of the Environmental Data and Information Service's "Key to Oceanographic Records Documentation No. 2, Temperature, Salinity, Oxygen, and Phosphate in Waters Off the United States" showed the density of data in this region to be representative of that in near shore regions along the east coast. Some 300 Nansen cast stations dating from 1966 to 1975 were included within this area.

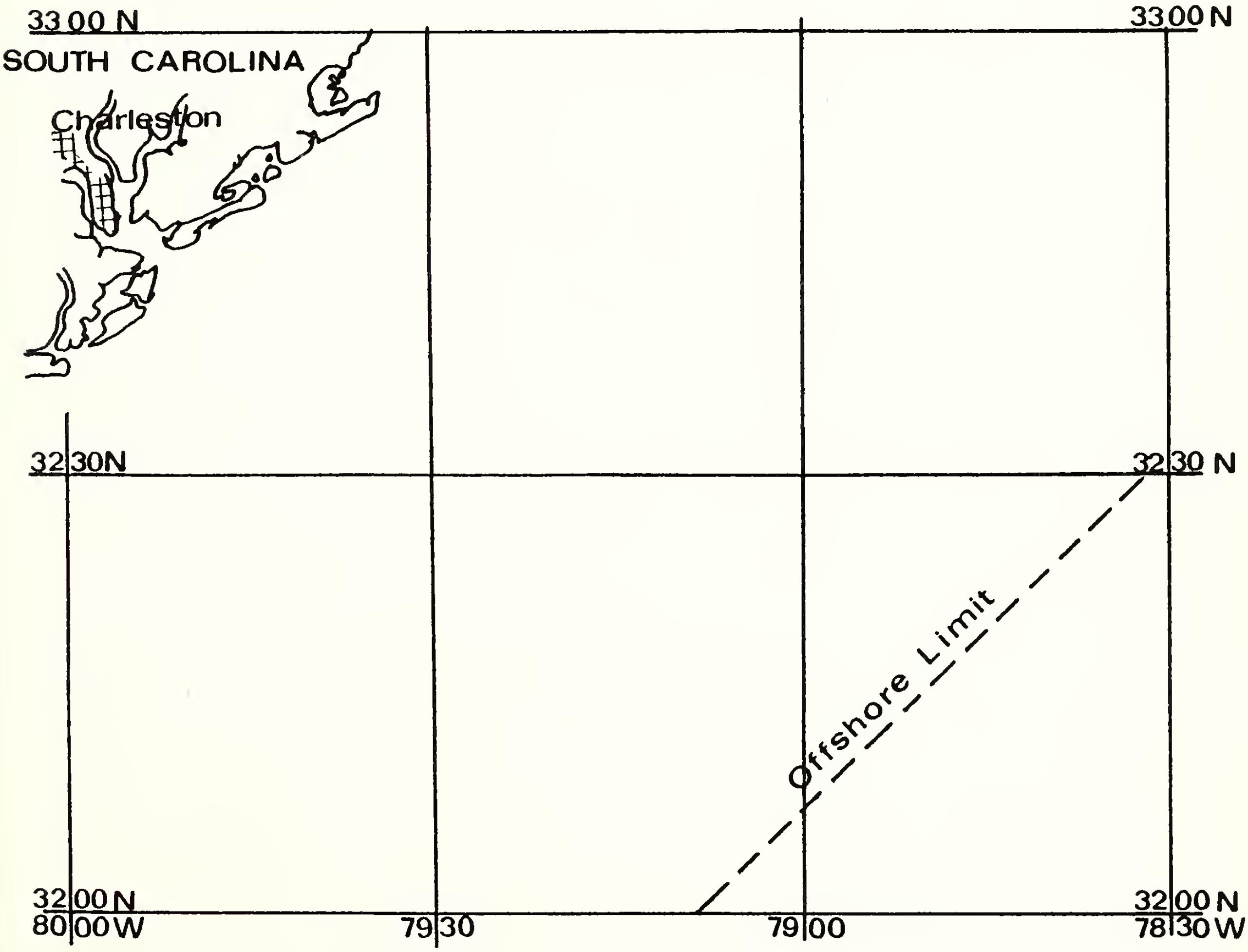

Figure 1.--Index map of study area.

DATA PROCESSING

In October 1978 NODC supplied a magnetic tape of all oceanographic (Nansen and STD) station data for the study area. A total of approximately 300 stations were within the area of interest. The data consisted of temperature, salinity, and sound speed (computed using Wilson's equation) for standard depths to the limit of observation for each station. Additional data included position, date, time, ship identification, and other parameters not examined. Where observations did not conform to standard depths, interpolations were made using a three-point LaGrange interpolation equation (NODC 1974). Sound speeds were not computed where temperature or salinity values were suspect or doubtful based on a preliminary data check by NODC (NODC 1974).

One basic statistical program (VELDAT) was written to summarize sound speed data. With slight modifications to this program, particularly in input format, programs were created to summarize salinity data (SALDAT) and temperature data (TEMDAT). All three programs had the same functions and produced similar results for each of the three variables examined.

Output consisted of a profile of mean sound speed, temperature, or salinity at standard depths; the standard deviation at each standard depth; number of samples included in the calculation; and location and values of maxima and minima at each standard depth for sound speed, temperature, and salinity. A sample standard deviation was also computed for sound speeds at each standard depth. Temperature data and salinity data were treated in the same manner.

This procedure of computing mean sound speeds and standard deviations at standard depths was suggested by the present NOS practice of using the "summation of layers" technique for sound speed corrections as described in the Hydrographic Manual.

PROCEDURE

The statistical programs were used to make an initial examination of the variability of sound speeds over the entire area by month. Lack of substantial numbers of observations during any particular month, however, precluded use of this technique for drawing meaningful conclusions.

Three-month seasonal groupings of data for the entire area were analyzed and found to exhibit larger variables than could be tolerated under the stated accuracy requirements. The question of applicability of historical data would have been quickly resolved had the variabilities over the entire area been small enough to match the stated accuracy requirements. Since this was not the case, a form of spatial subdivision was suggested by the locations of maximum and minimum values of the three variables examined--sound speed, temperature, and salinity. Because the objective was to separate the area into two natural populations of sound speed profiles, the study area was subdivided into two regions based on predictable variations of the physical properties of the water masses present (Kuroda and Marland 1973). The division was made along a northeast-southwest trending line approximately

parallel to the 18-meter depth contour (fig. 2). Analyses of sound speed, temperature, and salinity were made using the statistical programs (VELDAT, TEMDAT, and SALDAT) and the seasonal groupings previously cited for each area.

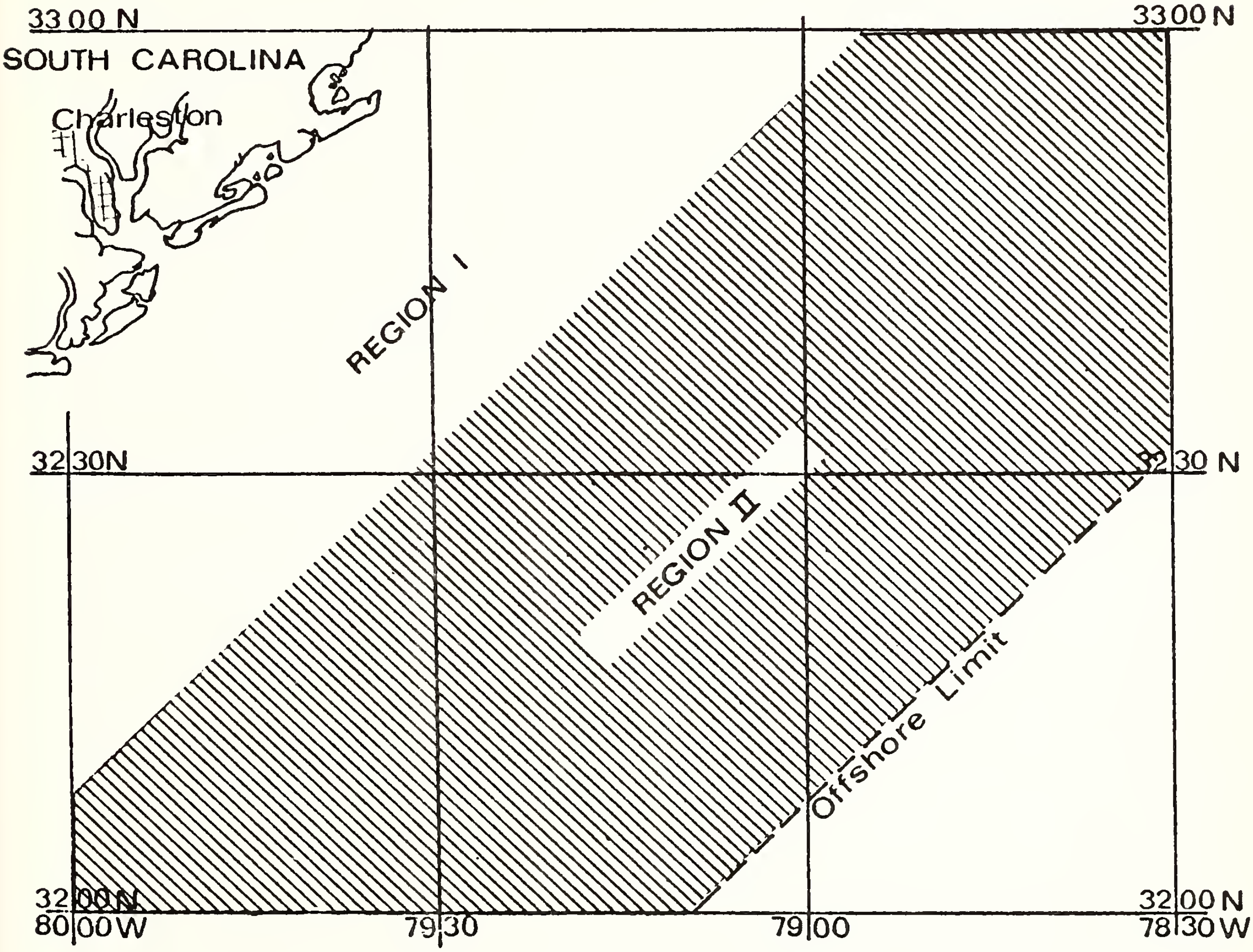

Figure 2.--Regional division of study area.

CONCLUSIONS

The results of the VELDAT analysis for Region I were less than satisfactory. Since the density of data in this region is low, sound speed profiles cannot be determined with any statistical certainty, and the use of this data for correcting echo soundings is not recommended. Direct, in-situ measurement of temperature, salinity, and depth for sound speed would have to be made. These findings were not extrapolated to other near shore regions on the east coast. Nevertheless, a cursory examination of the number of stations occurring in the near shore region of Marsden Square 116, of which the study area is a part, indicates that low data density in these regions will be a limiting factor.

Several conclusions can be made from the results of the analysis for Region II. NOS requires that mean sound speed be known to within $\pm$ 4 meters per second. Since the measurements for the parameters used to compute sound speed can vary, I feel that this NOS requirement logically can be interpreted to include 95.5 percent of the observations or a variability of two standard deviations (2σ).

Table 1 shows the value in meters per second of a 1σ variation at each standard depth computed using VELDAT for each season. This table also gives the value of a 1σ variation for salinity and temperature at each standard depth. Two standard deviations at any standard depth would exceed the required $\pm$ 4 meters per second value for sound speed, with the exception of the upper 10 meters during the summer. During the winter, all values for one standard deviation exceed the $\pm$ 4 meters per second requirement at all standard depths. The other seasons show values of one standard deviation which exceed the $\pm$ 4 meters per second requirement for some portions of the water column.

The variability of the historical data exceeds the $\pm$ 4 meters per second criteria at the 2σ level; hence, historical information is inadequate for echo sounding corrections. Data generated from this study indicated that changes in present methods for in-situ determination of sound speeds would be possible.

The least variable parameter affecting sound speed is salinity. Although the greatest standard deviation observed was 0.77 ppt, this was atypical. Standard deviations for the most part were in the range of 0.1 to 0.5 ppt.

The analysis of Wilson's equation (Bivins 1976) indicates that a natural variability of 3 ppt in salinity could be tolerated if temperature measurements were made with sufficient accuracy ($\pm$ 0.1°C). If 1σ variation in the range of 0.1 to 0.8 ppt were extrapolated to 2σ to include 95.5 percent of the values, the variability would not exceed 3 ppt. Therefore, temperature observations alone and historically determined salinities would appear to meet the stated accuracy requirements. Such temperature observations could be made more efficiently with the expendable bathythermograph system, instead of the currently used Nansen bottles with reversing thermometers and salinity, temperature, and depth probes.

Table 1.--Variability (1σ) of sound speed, temperature, and salinity

Depth (m)	Sound speed (m/sec)	Temperature (^{o}C)	Salinity (ppt)	Sound speed (m/sec)	Temperature (^{o}C)	Salinity (ppt)
		Winter			Spring	
0	5.4	1.85	0.10	4.2	1.72	0.77
10	5.3	1.84	0.10	4.1	1.75	0.61
20	4.9	1.70	0.32	3.6	1.71	0.23
30	4.9	1.69	0.12	4.1	1.56	0.21
50	4.5	1.53	0.14	2.8	1.03	0.15
75	4.4	1.69	0.14	2.6	0.87	0.18
100	5.7	1.81	0.20	3.2	0.97	0.29
		Summer			Autumn	
0	1.7	0.78	0.53	4.5	1.81	0.17
10	1.8	0.84	0.48	4.4	1.78	0.13
20	3.3	1.39	0.32	4.5	1.84	0.10
30	5.4	2.19	0.21	3.3	1.35	0.12
50	6.0	2.31	0.21	3.0	1.20	0.18
75	7.0	2.45	0.38	7.5	2.84	0.21
100	11.1	3.58	0.50	13.8	4.91	0.34

Finally, the data base used in this study indicated that near shore data for the study area were sparse. If this is characteristic of NODC files, improving the NODC data base would result in an improved determination of variability in the region.

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DISCUSSION

Mr. Ellis: Dave, you mentioned the void in the velocity corrections data that we have not deposited in NODC. There was some correspondence generated on this in the early 1970's. NODC tried to get all of our fathometer corrections data. We maintained at that time, and I believe it is still true, that we need the data as a part of the complete hydrographic package. We offered to loan NODC all of that data from back as far as we have it. They chose not to take it. They wanted the package to use it at their leisure, as their own.

Lt. Cdr. Yeager: The problem will continue to exist, I think.

Mr. Ellis: Oh, yes.

Lt. Cdr. Yeager: We probably ought to make some more efforts to see if we can't include it, because the NODC data base is a readily accessible base for a variety of organizations, and a variety of groups that could use this type of information.

Thank you very much.

FIELD OPERATIONS SEMINAR

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Individuals involved in both field and office phases of hydrographic surveying discussed various subjects of interest. Discussions were held in a general manner and served as a forum for identifying problems rather than finding solutions.

The following topics were discussed; where recommendations were made, they are included:

1. Software support for the HYDROPLOT system was examined. It was explained that there are existing support mechanisms for "real-time" or "on-line" programs in the present library. The National Ocean Survey's Office of Fleet Operations maintains the programs with the use of a contract programmer.

Changes to these programs may be requested via the software request forms. The proper routing for this request is as follows:

Field Origination
↓
Marine Center Processing Division
(review)
↓
Fleet Operations
(review)
↓
Marine Surveys and Maps
(accept or reject)

Non-real-time or off-line programs are not supported by any office in the National Ocean Survey (NOS) at present because other programming has been given high priorities, such as the Sea Beam, Swath Sonar, and Tides and Current programming. It was the consensus that off-line programs need to be supported, since the HYDROPLOT will continue to be in use for at least some time. Routines such as sounding selection programs similar to excess sounding routines are desirable, as well as software to handle digitized shoreline information which is expected to be delivered to the field soon.

2. General discussion was held on the chart products available from either Marine Chart Division or Requirements Branch to the field.

a. Presurvey review is automatically provided.

b. Prior survey data are automatically provided.

c. Chart blow-ups to survey scale are provided as requested.

d. Fixed and floating aids printouts giving positions and source data on aids to navigation will also be provided upon request.

The data provided have been an asset to the field, and the inclusion and availability of the "fixed and floating aid printout" were viewed as an excellent support service. Some field units have been unaware that this service was available.

3. In an effort to provide feedback, several common deficiencies with field surveys were noted and discussed, such as the lack of photographs for documenting evidence, particularly of alongshore features; incomplete and inadequate explanatory notes on field sheets, sounding volumes, and printouts; and not meeting the requirements for use of properly documented horizontal control and its mandatory submission into the NGS system.

4. Status of chart evaluation surveys (CES) was explained by Marine Requirements Branch and certain features of this program were underlined.

a. Item resolution has become the most important aspect of CES.

b. Future efforts will ensure that hydrographic ships will not be assigned CES work that can be accomplished by shore-based parties.

c. Item resolution standards for CES must be the same as standards set for basic hydrography.

5. Wire drag techniques for small boats were discussed and requirements for such techniques were expanded upon by Marine Requirements Branch.

a. In effect, small boat techniques must meet wire drag standards set forth in the Wire Drag Manual, which include lift testing and documenting area dragged as well as effective bottom clearances.

b. Future project instructions will specify the requirements necessary to resolve a given item.

c. Additional comments were noted concerning deficiency of source data files on wrecks and obstructions in NOS.

d. Bottom drafting techniques were discussed.

6. Status and purpose of Hydrographic Guidelines promulgated by Marine Surveys and Maps were explained. The purpose has been to put out information on changing requirements and methods in this form until such data can be incorporated into the NOAA Hydrographic Manual (Umbach 1976). These guidelines should be filed with the NOAA Hydrograhic Manual (Umbach 1976) and used to emphasize, interpret, and supplement material presently in the Manual.

7. A brief discussion was held on the Coast Pilot Manual (U.S. Coast and Geodetic Survey 1969). It was generally agreed that this subject needed re-emphasis in the field. Additionally, the Coast Pilot Manual (U.S. Coast and Geodetic Survey 1969) is presently under revision, and input was requested from the field.

These discussions were intended to identify areas which have been perceived as problems by both field and office units concerned with field methods and procedures.

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CHANGES IN HYDROGRAPHIC SURVEY TECHNIQUES IN THE 1980's

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ABSTRACT. Technological advances will permit development of hydrographic survey techniques that will increase the quality and accuracy of survey data and expedite that data from the field to the cartographer. Digital data bases, fully automated acquisition, swath sounding, and airborne laser hydrography will require refinement of survey specifications and improved monitoring and control of parameter errors. A major impact will be felt in the methods and procedures of hydrography.

INTRODUCTION

During this conference other speakers will discuss several new systems, equipment items, and techniques that are expected to contribute to the improvement of hydrography in the National Ocean Survey (NOS). These include dual-beam echo sounders, photobathymetry, possible new techniques for sound velocity and tide corrections, heave/roll/pitch (HRP) sensors, the Automated Information System (AIS), laser hydrography, and the Global Positioning System (GPS). A variety of other developments currently in progress are not mentioned, such as the swath sounding systems, a new data logger for small boat application, a shallow draft survey boat, a new generation of tide gages, telemetered tides, digitized photogrammetric data, the geodetic data base, and the planned replacement of HYDROPLOT.

Even a cursory review of these items shows the dramatic impact their operational implementation will have on almost all aspects of marine charting. They will affect survey requirements and planning, procedures and documentation, data quality control, and personnel levels, skills, and training. The charting system's data handling capacity may well be strained beyond its limits. A more in-depth look shows the complexity of the impact. One development will require one or two others, or in some cases, a new development in one system will suggest its application in another. A few examples will illustrate these points.

Swath sounders and laser hydrography function, in effect, as several conventional echo sounders in one and will deliver a correspondingly increased amount of data during a given period of time. In the laser system's case this amount may be massive, due to the rate at which the data are acquired. The marine charting system must be able to absorb and utilize this increased volume of data. Both systems incorporate a high level of automatic corrector application, data analysis, and data selection in the acquisition process. It

is clear that conventional verification procedures cannot be applied, and that completely new mechanisms for assuring data quality must be developed and certified.

Laser hydrography promises to survey immense shallow water areas primarily along the east coast. It will, however, not be able to cover the deeper water portions of survey areas and, therefore, completion of surveys must depend on vessel survey operations. Tides support and, possibly, ground positioning and data processing will have to be provided. Consequently, a new dimension will be added to survey planning and coordination.

HRP data are essential to swath sounding data acquisition, among other reasons, to eliminate the vertical motion of the sounding vessel with respect to the current mean water surface. Application of this method to conventional sounding systems would eliminate one of the prime reasons for manual scanning of echo sounder records; application of sounding selection routines, also part of swath sounders, would eliminate another. Full utilization of digital data bases by delivering survey reference data in digital machine processable form would obviate the need for manual application of that data to various survey documents.

PLANNING FOR NEW SYSTEM IMPLEMENTATION

It is apparent that new technology, driven principally by advances in digital data processing, can contribute much to the improvement of NOS' marine charting operation, both in the quality and timeliness of its products and in the efficient utilization of manpower and other resources. This will, however, require that application and implementation of new systems and techniques be carefully planned and coordinated. Unfortunately, and rather characteristically, present development efforts focus primarily on <u>technical</u> aspects without concurrent adequate attention to <u>operational</u> ramifications. In addition, the efforts largely stand alone, each addressing one particular problem or aspect of the total system; they lack a common set of goals or a focal point for integration.

This is at least in part due to the fact that no single organizational element in the Office of Marine Surveys and Maps (MS&M) has the responsibility for coordinating development efforts, establishing priorities, weighing benefits against costs or the agency's resources, matching new capabilities with real needs, or generally identifying the direction of the organization's growth. The fact is that many of the development initiatives come from outside the marine charting organization, and there have been occasions when new equipment was operationally deployed without the organization's active involvement. If problems resulting from these events have so far been resolved with reasonable success, the range and scope of current developments forebode serious consequences if proper plans are not made for their operational implementation.

In recognition of this problem, the Associate Director, MS&M, recently instructed his Division Chiefs to convene under the chairmanship of the Deputy Associate Director to propose:

(1) the mechanism and organizational responsibilities within MS&M for the control and continued development of the marine charting system,

(2) general policy objectives for that development.

Deliberations will consider the current and anticipated line of marine chart products: the ultimate result of all work. Constraints of traditional methods and procedures per se have been lifted, a critical point if modern techniques are to be applied effectively. The intent is a total objective look at the marine chart production system.

The results of the group's efforts are immediately needed for the development and implementation of three major systems. The Bathymetric Swath Survey System (BS^3) is coming ever closer to operational deployment, and suitable data quality control mechanisms have yet to be established. Laser hydrography has been demonstrated to be feasible and has been given the go-ahead for full-scale development; procedures for data quality control and processing must be provided soon and plans made for the system's deployment. The replacement system for HYDROPLOT is expected to be funded as early as FY 1981. System specifications that may or may not incorporate new methods and techniques must be formulated immediately; those specifications will materially affect the nature of vessel hydrography for some years to come.

In the absence of defined policy objectives, it is difficult to forecast future development of hydrography in NOS with precision. It is, however, interesting and perhaps constructive to consider the possibilities, if only to elicit the thoughts, comments, and suggestions of personnel throughout the organization. The concept contained in the following sections should, therefore, not be construed as approved objectives of NOS.

CHARTING REQUIREMENTS

Requirements for chart products must be defined if the ways and means of acquiring necessary data are to be addressed. There appears to be increasing demand for charts other than conventional surface navigation charts. These include precise bathymetric charts for offshore engineering, pollution monitoring and hazards warnings, charts depicting bottom characteristics and hazards to be used for commercial fishing, and perhaps special navigation charts for deep-draft vessels, port approaches, and charts in new formats and with more frequent updates. In general we must continue to strive to produce charts that are as accurate, up-to-date, and timely as possible, and serve the intended uses. Concurrently we must improve the utilization of limited resources, particularly in the area of manpower levels and skills. How can new technology and techniques contribute to the attainment of these objectives?

AUTOMATION

Transfer of routine tasks to machine accomplishment can significantly reduce tedious and time-consuming manual tasks and will induce consistency and objectivity in measurement and analysis processes, thereby increasing the reliability and repeatability of data. The determination and application of

data reducers or correctors can and should be automated. In the case of positioning data this will be accomplished by observing more than two lines of position (LOP's) and eliminating the need for time-consuming calibration routines. Automatic application of HRP data to raw soundings will eliminate one reason for scanning fathograms and the subjective extraction of wave effects from the data. Where necessary, correction for pointing error associated with narrow beam sounding will be made. Measurement of the sound velocity structure by expendable probes will realize savings in shiptime, manpower costs, and instrument calibration costs. Correction for sound velocity will be enhanced by the convenience of this measurement technique and the increased detail and precision of the corrector data delivered in machine processable form. Telemetered tide reducers, coupled with improvements in tidal zoning and datum determination, will speed sounding data through its processing and quality assurance phases.

Improved computer data selection routines must be implemented that will utilize all observations and derive reduced data sets for specified applications. This may involve more than one process to select data for bathymetric and nautical charts, for instance. Most certainly these routines will depart from the convention of selecting data according to elapsed time along the sounding line and will instead relate to geographical distances or spaces. Properly designed selection mechanisms will eliminate another reason for manual scanning of fathograms.

Digital data bases will be further integrated in the hydrographic process by delivery of survey reference data from these bases to the hydrographer in machine processable form. (Generation of survey data in this form is already established.) These data may include existing charts of the survey area; prior surveys; topographic, photogrammetric, and geodetic information; as well as presurvey review items and other survey specifications. This process will eliminate the need for tedious hand copying of information on various survey sheets and will facilitate automatic comparison of new data with old, geodetic control planning, and perhaps the field edit process. Data analysis must be automated, particularly if increasingly larger volumes of data are to be handled. This could include testing for internal integrity of the data, comparison against historical data, junctioning with adjacent surveys, or testing against acceptable theoretical models of the survey area. In the end it may evolve that, as a result of comparisons against existing charted information, only the observed changes, anomalies, and new data are forwarded for incorporation in the data bases, rather than the complete survey data package. This could significantly ease the workload on the cartographic staff.

SPECIALIZATION

Wire drag operations and circulatory surveys have already been identified as specialties, assigned to dedicated ships, and largely removed from the scope of combined operations. This followed from the sophistication of instrumentation and the special skills required of the operators. Swath surveying and laser hydrography can soon be added to the list and perhaps eventually underwater sonar search. There is little doubt that specialization leads to increased operating efficiency, improved data quality, and reduced requirements for training. Specialization may further be reflected in the

evolution of a building block concept in chart assembly, since different charts utilize specific combinations of a limited number of data types. Separate storage of these data types and subsequent assembly according to stated requirements should allow the production of any kind of marine chart. This concept has, to a limited degree, been introduced in the AIS in the form of so-called overlays, each of which contains a defined subset of the total data required to produce a nautical chart.

Specialization aids the application of specific survey tools and capabilities to the requirements of a particular survey, possibly through the formation of a task force. This could be as small as one ship outfitted with particular equipment, launches and personnel, or could encompass several ships and aircraft, in which case additional benefits of combined shore support would be gained, including vertical and horizontal control support, field edit and data processing, for example. The economic advantages of dedicated intensive survey efforts should be given more attention.

FOCUS ON CHARTING REQUIREMENTS

A further step toward more economic use of survey resources is the adaptation of survey specifications to the real charting data requirements. Present survey specifications are extremely rigid and, to some extent, arbitrary. Sounding line patterns as well as spacing between soundings and data accuracy are prescribed primarily on the basis of chart scales and water depths; basic surveys require that all areas be covered to the shorelines. Changes in the latter, the survey coverage, have already been made in the form of chart adequacy and navigable area surveys. It would appear that more effective use of survey resources could also be realized by relaxing or tightening requirements for data precision and density as a function of more practical parameters, such as the characteristics of the bottom and the geographic nature and economic significance of the area, for instance. This would beneficially affect not only the time required to run survey lines and process data, but also the time and effort required to establish positioning and tide control. Detailed survey specifications would have to be included in the project instructions.

In a similar vein, search patterns should be designed and certified that will, in a finite amount of time, disprove reported submerged obstructions to an acceptable level of confidence. The effectiveness of this concept would depend on the knowledge of the search instrumentation and operators' skills.

Finally, the end product of a survey should be redefined. The possible elimination of the smooth sheet and perhaps various printouts and reports as necessary products may save considerable time and effort. The smooth sheet as the analytical tool for survey data evaluation will, in the long run, no longer be necessary, since data analysis will be accomplished by mathematical techniques. As a reproducible product it will be replaced by the AIS chart production system, and as the means for transferring data from the survey area to the cartographic data base it will become superfluous, since that transfer will take place by digital data tapes.

DATA QUALITY CONTROL

Existing data accuracy specifications are stated very imprecisely. As a result, it is nearly impossible to say whether any acquired data meets them or to evaluate the performance potential of new instrumentation systems or subsystems. The specifications must be restated in terms of statistical error limits and confidence intervals. Here again, consideration should be given to adapting accuracy standards to the real requirements of charting data and the intended use of that data.

As indicated earlier, it is inevitable that data quality must be assured at the acquisition process in the cases of such complex systems as swath sounders and laser hydrography. It is reasonable to extend this concept to all forms of data acquisition in order to standardize the management of all data and to reduce the time and manpower required for post-survey verification; modern data processing facilities will make this possible. In the end it is desirable to return to the hydrographer the authority and responsibility for survey accuracy and completeness. Techniques for quality assurance may include analysis, verification and calibration of sensors, frequent performance verification of the complete data acquisition and processing system, certification of computer programs, strict adherence to specified procedures, and meticulous documentation.

In a more general sense, the detailed performance of all equipment must be understood and accepted, and the utilization of the equipment controlled. Hydrographer training must emphasize the application and operation of survey tools and the reasons for relatively rigid controls over procedures and documentation. Organizational elements responsible for quality assurance must be redirected to the analysis of equipment and software functions, preparation of operating procedures and documentation requirements, operator training, verification of compliance with procedures, and only limited inspection of survey products.

The certified accuracy of data should be continuously tracked and noted, particularly if variable accuracy standards are implemented. Knowledge of accuracy should increase the utility and value of data.

MANAGEMENT AND PLANNING

As noted earlier, proper management is probably the most important element in the development of hydrography, the implementation of new and ever more sophisticated systems, and the inexorable shift from manual methods to automation. Objectives must be established, responsibilities clearly assigned, priorities set, decisions made, and coordination applied to actions that may simultaneously affect several components of the charting system. The performance of the system must be monitored with an eye toward coordinated scheduling, data flow, and timely production. Continuous attention must be given to detecting deficiencies or opportunities for improvement; suggestions and proposals must be actively solicited. Limited resources must be judiciously utilized in the light of known objectives and priorities, developments monitored and controlled, and implementation plans made and carried out.

Management attention within MS&M must be focused on operational or functional requirements, yet sufficient technical expertise and capacity must be maintained to handle small-scale upgrades and modifications of existing systems and to direct development of new systems that will undoubtedly be carried out by organizations outside MS&M.

REPLACEMENT SYSTEM FOR HYDROPLOT

A few comments may illustrate how the above described changes may be implemented in the next generation of vessel hydrographic systems. The replacement of HYDROPLOT will result from an initiative of the Office of Fleet Operations to replace all computer systems in the fleet, principally to resolve anticipated maintenance problems, but additionally to standardize equipment and software to the maximum extent. The hydrographic version of this fleet standard has been tentatively dubbed "P80" (for Post-1980).

One of the overriding objectives will be to incorporate adequate capacity for universal application, flexibility, and growth; to simplify operation and programing; and to maximize reliability within the constraints of available resources. High level programing language will be specified, as well as operating systems to support multiprograming and multitasking, possibly disc stored to ease program loading. Magnetic tape will be the data storage medium.

Sensor systems will be incorporated as distinct subsystems to permit their individual modification or upgrading as necessary. In the case of the positioning subsystem, this will include the utilization of multiple LOP's in any selectable combination of positioning systems, such as SHF and HF electronic, or visual azimuth or digital sextants. If GPS is eventually adopted for hydrography, it can be substituted as the entire subsystem. The echo sounding subsystem may consist of a conventional single-beam echo sounder, a swath sounder, or multiple single-beam sounders. HRP sensors and telemetered tides will be planned for future wide-scale incorporation; eventually full-scale automatic corrector application should become part of the system.

The facility should include the capacity to receive, store, and display digital source data discussed earlier. It is expected that graphics terminals will find wide application in all systems, coupled with hard copy print capability to generate working graphics documents. Consideration is being given to extending data storage capacity to launch systems to establish the capability for virtual real-time data processing and quality verification. This could significantly speed up data processing during consecutive days of survey operations and would provide the launch hydrographer with the necessary information to plan and conduct his surveys as effectively as possible.

Ships' processing system capacity will undoubtedly be significantly larger than that of launch systems, since it must support concurrent reformatting and editing of several batches of survey data, generate hard copy printouts and plots, and carry out other utility tasks.

CONCLUSION

The foregoing concepts and thoughts only scratch the surface of technical and operational considerations in the evolution of hydrography, but perhaps they paint a general picture of the possibilities. Clearly, the potential exists for major strides toward improved utilization of survey resources and the production of improved and new marine charts.

HEAVE-ROLL-PITCH CORRECTION FOR HYDROGRAPHIC AND MULTI-BEAM SURVEY SYSTEMS

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ABSTRACT. One of the major sources of errors in bathymetric and hydrographic surveys arises from uncompensated vessel motion--heave, roll, and pitch. Tedious and subjective interpretation of graphic echogram records has been the only means hydrographers have had to cope with these errors. Often, obstructions and true bottom features are rendered indistinguishable from these motion-induced artifacts. This problem has precluded the true automation of hydrographic survey data processing. On multi-beam swath mapping systems, accurate vessel attitude data are an absolutely vital ingredient in reducing multi-beam data to accurate depth measurements.

This paper describes the efforts undertaken by the National Ocean Survey and Datawell bv. of the Netherlands to develop instrumentation to measure and compensate for vessel motion. The design and field testing of two different developmental instruments are described. Theoretical and practical performance limitations of each of the two designs are discussed.

An operational Heave-Roll-Pitch Correction System--HIPPY-120--evolved from the Datawell development effort. The Datawell HIPPY-120 has been operational for over a year as an integral part of the Bathymetric Swath Survey System (BS^3) on the NOAA Ship DAVIDSON. The design, performance, and operational constraints of HIPPY-120 are described. Additionally, the integration effort of HIPPY-120 into the BS^3 is described as well as the usage of Heave-Roll-Pitch data in the reduction of BS^3 multi-beam data to vertical depths.

INTRODUCTION

One of the major sources of errors in bathymetric and hydrographic surveys arises from uncompensated vessel motion--heave, roll, and pitch. Tedious and subjective interpretation of graphic echo-gram records has been the only means hydrographers have had to cope with these errors. Often, obstructions and true bottom features are rendered indistinguishable from these motion-induced artifacts. Figure 1 illustrates the problem; the Ross echo-gram shows a sounding line reversing direction. Notice the abrupt change in character of the trace as the line changes direction. What parts of this trace are bottom features, and what parts are motion-induced artifacts? It is impossible to tell from the echo-gram alone. With single-beam vertical sounders we are at least able to perform an eyeball smoothing--tedious and subjective as it might be. With multi-beam swath sonars, motion-induced errors are much more serious. Accurate vessel attitude data are absolutely vital in reducing multi-beam data to accurate depth measurements.

OCEAN WAVES

Before addressing the problem of measuring and correcting for vessel motion, it will be useful to discuss the forces that cause these motions--ocean waves. Ocean waves fall into three broad categories: tides, long waves, and wind waves. Tides are waves having periods that range from 1 to 24 hours. The problem of measuring tides was solved by Lord Kelvin with his invention of the recording tide gauge in 1882. Gauges of his design are still in use by the National Ocean Survey. The second category, long waves, have periods from 1 to 60 minutes and include tsunami, seiche, and shelf waves. These long-period waves will not be addressed in this discussion, although their influence on some surveys could be significant.

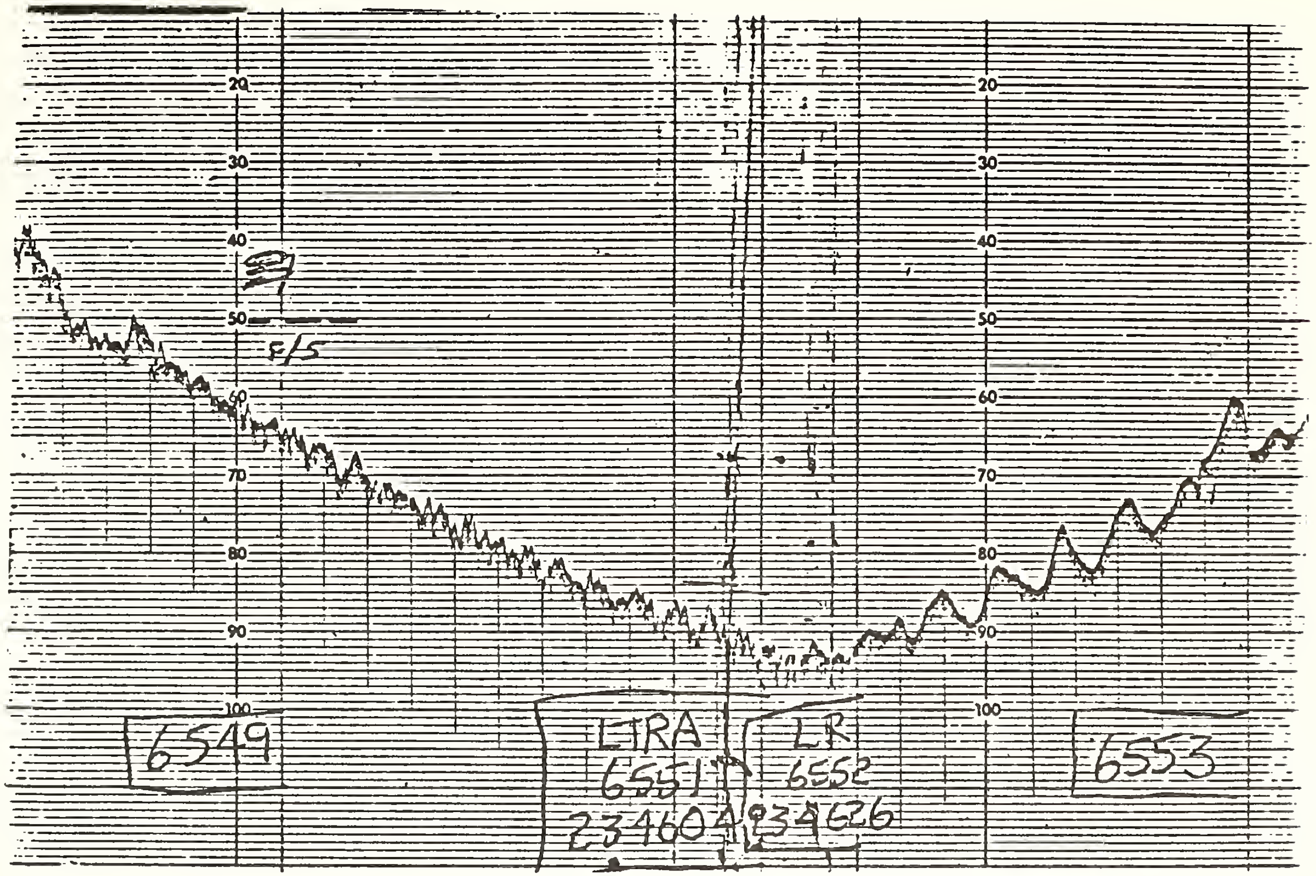
The waves that cause the vessel motions that we are concerned with are wind waves. Their periods range from 1 to about 20 seconds and their heights range up to 20 meters. Waves travel along the surface of the ocean at speeds proportional to their periods. This relationship is given by the equation:

$$C = T \cdot g/2\pi$$

where C is the speed of propagation, T is the wave period, and g is the gravitational constant. For example, a 5-second period wave travels at 15 knots, while a 10-second wave travels at 30 knots. This relationship is somewhat modified when waves enter shallow water where the maximum speeds are limited to the value:

$$C = \sqrt{g \cdot d}$$

where d is the depth of the water. It is important in what follows that we understand the association of wave period to the propagation speed of the wave.



Ross Fathogram

Figure 1.--Depth record showing differences in the trace with a change in direction of the sounding line.

Typically, open coastal waters are characterized by an average significant wave height of 2 meters and a wave period of 5 to 10 seconds. Figure 2 is an example of the distribution of wave periods and energy for a 1-month period at four different California coastal monitoring stations. Notice the variability from day to day, as well as the differences from station to station. This is the environment we must deal with in measuring and correcting for vessel motion.

DOPPLER EFFECT

If our task were only to measure wave motion, then we would only have to concern ourselves with motions having periods ranging from 1 to 20 seconds. For a given sea condition (wave period), a vessel running with the sea will experience a longer heave period, and a vessel running into the sea will experience a shorter heave period than the heave period of a vessel not under way.

Vessel heave periods can differ drastically from the periods of the waves inducing the vessel heave, depending upon the speed and course of the vessel with respect to the direction of wave propagation. This is a Doppler shift and is given by the expression:

$$T = \frac{\Upsilon}{1 - \frac{s}{c}}$$

where T is Heave period
Υ is Forcing wave period
c is Phase speed of forcing wave
s is Vessel speed in direction of wave

This Doppler phenomenon is the source of the real technical difficulty in designing and using a heave sensor.

The design of a practical heave sensor should provide for the widest possible bandwidth of heave periods. Once the bandwidth of the instrument is specified, then its operational envelope can be defined. The instrument will accurately measure vessel heave motions within the instrument's bandwidth envelope and will be incapable of measuring heave motions that fall outside that bandwidth.

Figure 3 illustrates the operational envelope for two different bandwidth instruments--30 seconds and 60 seconds. The horizontal axis represents the prevailing wave period. The vertical axis represents the component of speed of the surveying vessel in the direction of wave propagation. Vessel operation is permitted in the upper and the lower regions, but prohibited in the crack that separates these two regions. Notice that the crack associated with the 30-second instrument is wider than the crack associated with the 60-second instrument--the 30-second instrument has a larger prohibited area. A vessel that is operated inside the prohibited area is in a "near surfing" condition, and the heave instrument will not correctly measure the vessel's heave motion. Notice that no matter how wide a bandwidth an instrument might have, there will always be a prohibited area.

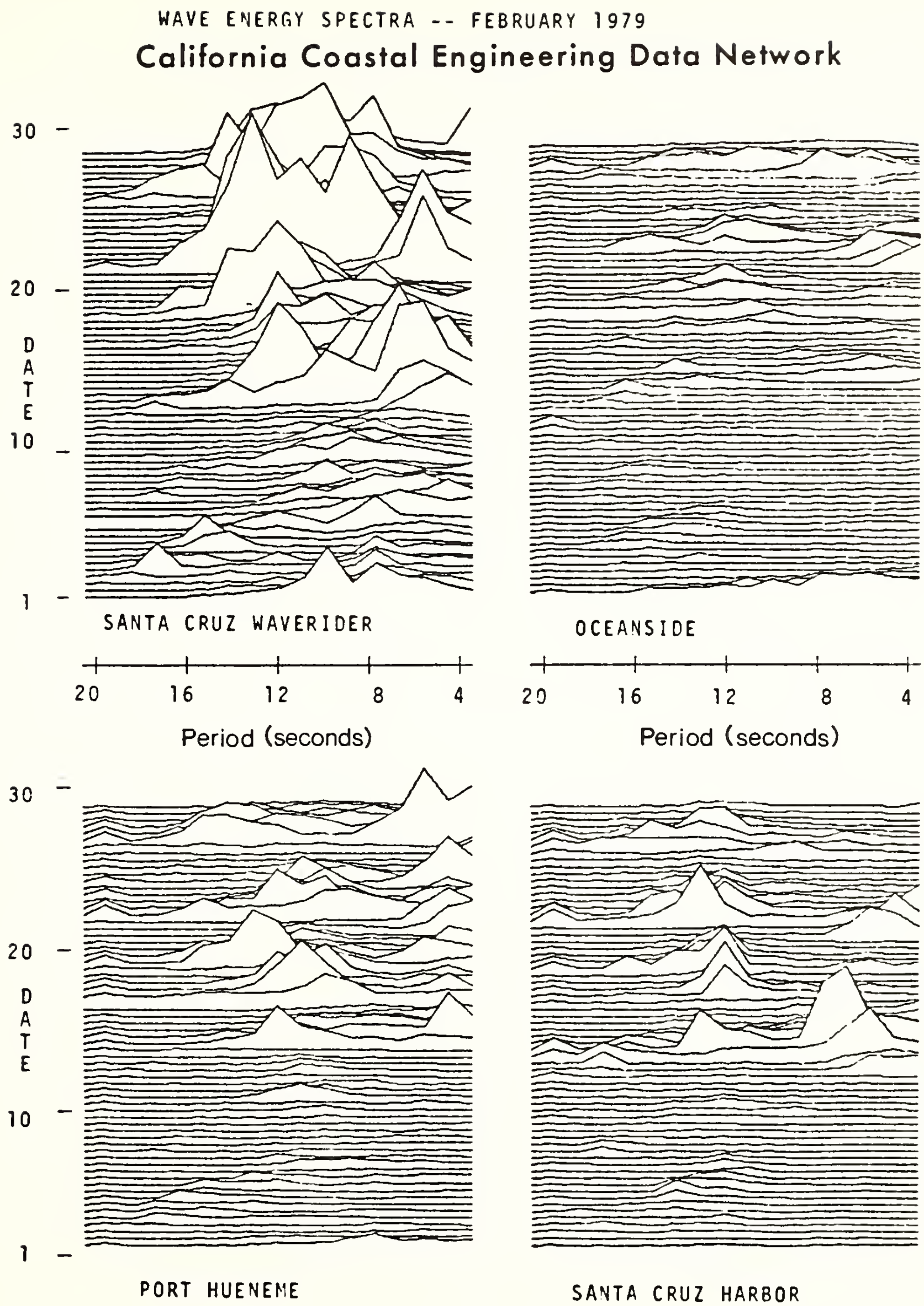


Figure 2.--Examples of distribution of wave periods and energy.

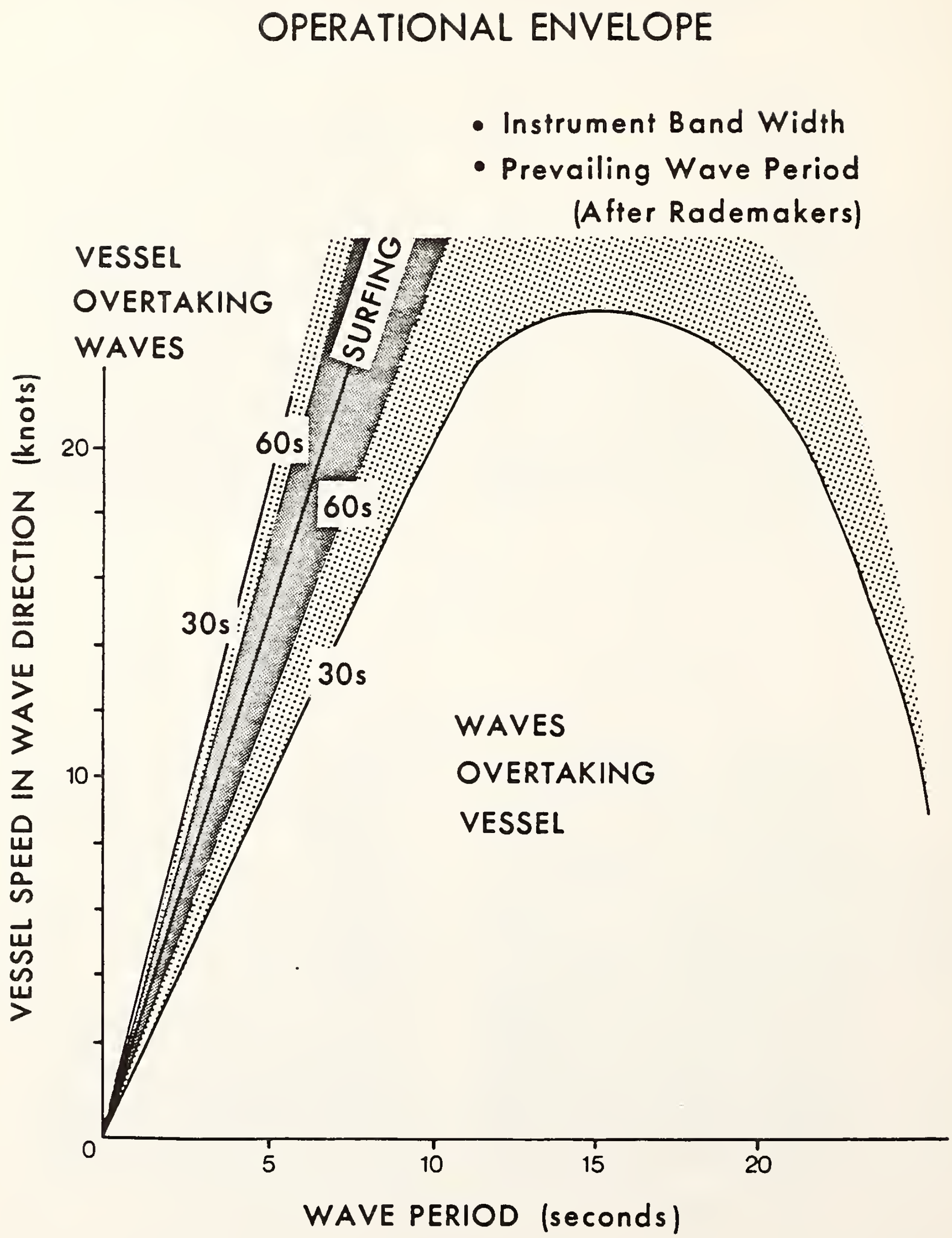


Figure 3.--Operational envelope for two different bandwidths.

Notice also that is is always possible to move from the prohibited area into a safe region by slowing the vessel's speed until the waves are overtaking the vessel with sufficient frequency to ensure that the vessel heave period is within the band of the instrument. No matter what design or bandwidth a heave instrument might have, these operational constraints will always apply. Survey personnel must comply with these constraints if heave compensation is to be performed correctly. Although these operational constraints may appear at first to be cumbersome, they should apply equally to surveys conducted without heave compensation instruments. It is quite easy to introduce large undetectable errors into survey data by operating the survey vessel in a surfing condition.

RECIPE FOR HEAVE-ROLL-PITCH CORRECTION

In addition to heave, the vessel's roll and pitch must also be measured if it is desired to correct sounding data for all motion-induced errors. In measuring heave, we must be satisfied with heave measurements confined to some specified band of heave periods, then operate the vessel accordingly. In measuring roll and pitch, we cannot tolerate such constraints--we must be able to accurately measure roll and pitch from DC to the highest frequency of motions experienced by the vessel. Fortunately, this is not a problem.

Let α represent the pitch angle, β represent the roll angle, and γ represent the combined pointing angle--the angle between the vessel's truck and the true vertical. Figure 4 shows the geometry involved in making the heave and pointing angle corrections for a single beam vertical echo sounder. Vessel heave, roll, and pitch must be measured both at ping time and receive time to make the correction properly. Notice that not only is there a correction to the observed echo range, but also there is a displacement in the position of the sounding. In shallow water, the heave correction will dominate, and the pointing correction will be insignificant. In deep water, however, the situation is reversed--pointing corrections can be significant, while the heave correction will be a very small percentage of the depth.

There is yet another correction that must be applied, the translation correction. It is usually not possible, nor is it desirable, to locate the heave sensor in the same location with the sonar transducer. Because of this, the sonar transducer experiences a heave motion that is generally quite different from the heave motion experienced by the heave sensor. Fortunately, it is a straightforward exercise in geometry to determine the transducer heave, given roll, pitch, and sensor heave, and the X-Y-Z offsets of the transducer relative to the location of the heave sensor. The recipe is:

$$H_T = H_H + X \cdot \sin\alpha + Y \cdot \sin\beta + Z \cdot (1 - \cos\gamma)$$

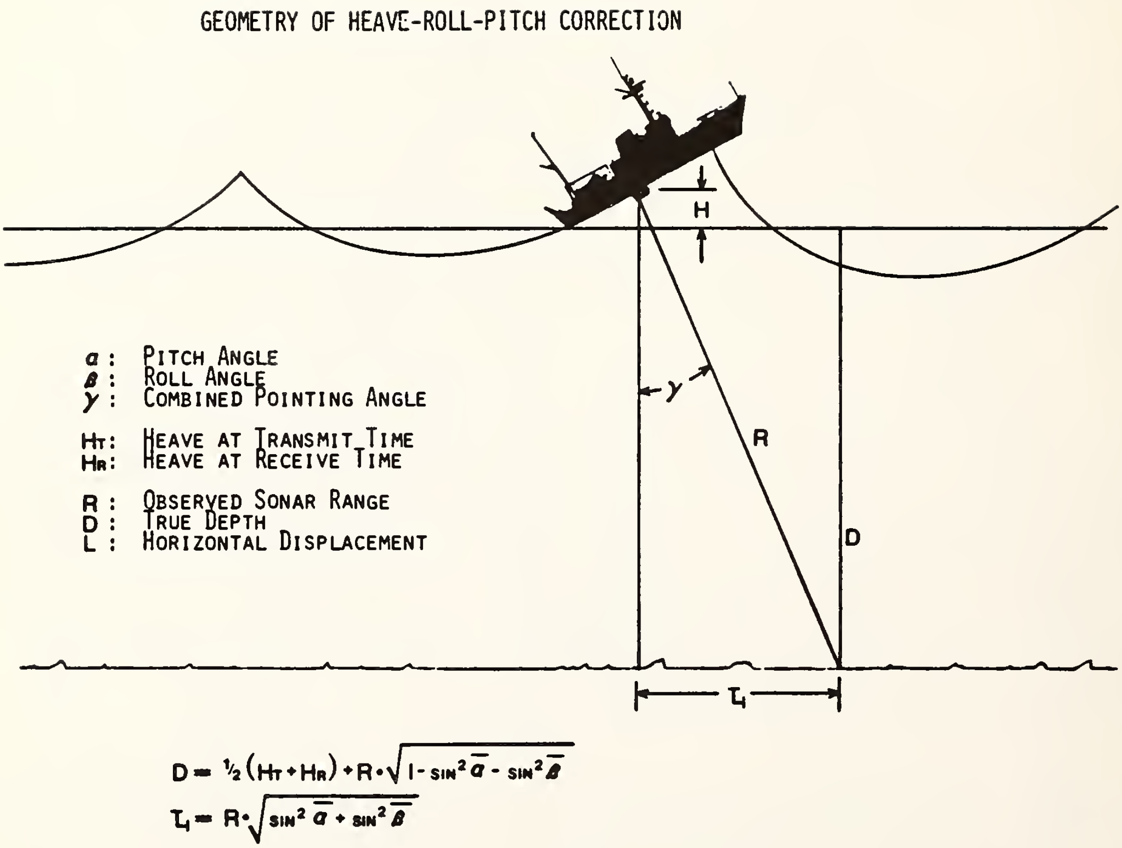


Figure 4.--Geometry involved in making heave and pointing angle corrections.

where H_T is transducer heave

H_H is measured heave

X is fore-aft sensor-transducer displacement

Y is athwartships sensor transducer displacement

Z is vertical sensor-transducer displacement

This translation correction must be determined and applied both at ping time and at receive time.

On the surface it would appear that making heave-roll-pitch corrections to sounding data is an exceedingly messy and complicated affair. In practice, however, it is a straightforward effort to program these functions into a digital computer. Of course, all of the sonar and heave-roll-pitch data must be available to the computer in a digital format. Such a system has been in service for over 2 years on a NOAA survey vessel.

HEAVE MEASUREMENT TECHNIQUES

In 1974, Arthur D. Little, Inc., conducted a study to identify viable technical alternatives for measuring vessel heave. Techniques considered by this study included: barometric sensors, gyro stabilized platforms, pendulum devices--both short and long period--and a strap-down inertial platform. The study identified two viable approaches, the long period pendulum and the strap-down inertial platform. Based on the recommendations of this study, the National Ocean Survey undertook the development of a strap-down inertial platform, contracting to Arthur D. Little for the design and construction of an engineering model. Independent of this effort, Datawell bv. of the Netherlands was pursuing the development of a long-period pendulum device based on the design used in its Waverider buoy.

Figure 5 is a table that summarizes the findings of the A. D. Little study. In addition, this table tabulates the results of field tests conducted to evaluate the various techniques under actual field conditions. These tests confirmed the findings of the A. D. Little report. It should be pointed out that the unsuitability of the two Humphrey instruments does not reflect poor design, but rather, it demonstrates that the instruments were used outside of their design envelope as the A. D. Little study correctly predicted.

ARTHUR D. LITTLE DESIGN

The Arthur D. Little instrument makes use of three linear accelerometers, three angular rate transducers, and an elegant mathematical algorithm to derive a measure of roll, pitch, and vertical acceleration. The vertical acceleration is then doubly integrated and filtered to provide a measure of heave in the band of interest. This design has the advantage of being compact, light weight, and having no moving parts. Potentially, this design could offer the widest heave bandwidth--limited only by sensor noise. The instrument built by A. D. Little had a heave bandwidth of 20 seconds and used analog electronics.

HRP MEASUREMENT TECHNIQUES

DEVICE	FEASIBILITY	ENG. MODEL	PROTOTYPE	OPERATIONAL
BAROMETRIC	REJECTED ADL 1974			
VERTICAL GYRO	REJECTED ADL 1974	HUMPHREY SA-09 TESTED 6/76 UNSUITABLE		
SHORT PERIOD PENDULUM	REJECTED ADL 1974	HUMPHREY VI-10 TESTED 6/76 UNSUITABLE		
LONG PERIOD PENDULUM	CANDIDATE ADL 1974	DATAWELL TESTED 6/76 SUCCESSFUL	DATAWELL HIPPY 120 IN SERVICE JAN 1978	DATAWELL HIPPY 120 DELIVERED JAN 1980
ADL STRAP-DOWN SENSOR	CANDIDATE ADL 1974	ADL HRP TESTED 6/76 SUCCESSFUL	ABANDONED IN FAVOR OF NOS ENGINEERING DEVELOPMENT LABORATORY DESIGN	
EDL STRAP-DOWN SENSOR	STARTED 10/77	PENDING		

Figure 5.--Summary of A. D. Little, Inc., findings and results of field tests.

DATAWELL DESIGN

The Datawell instrument makes use of a cleverly designed platform whose motion is characteristic of a pendulum with a period of 120 seconds. This platform provides a stabilized vertical reference. An accelerometer mounted on this platform provides a measure of vertical acceleration which is doubly integrated and filtered to provide a measure of heave. Roll and pitch angles are measured to a resolution of 0.1° by reference to the stabilized platform. The prototype instrument--in service now for 2 years--features an imbedded microcomputer. It performs signal processing and manages data communications with the survey system data logger. The heave output available in real time has a bandwidth of 15 seconds. Heave with a bandwidth of 30 seconds is available, but delayed in time by 70 seconds.

FROM VERTICAL ACCELERATION TO HEAVE

From a mathematical perspective, the A. D. Little and Datawell designs are very similar. Both instruments provide a measure of vertical acceleration. The vertical acceleration is then filtered and then doubly integrated to provide the desired heave. Because of the double integration, any low frequency noise in the vertical acceleration will result in errors in the computed heave. It is, therefore, necessary to filter out this low frequency noise before the integration is performed. The source and nature of this noise depend upon the instrumentation technique, but will exist in every instrument. In the Datawell instrument, this noise occurs at the second harmonic of the pendulum and has a period of 60 seconds. In the A. D. Little instrument, thermal noise generated in the angular rate transducers finds its way into the vertical acceleration. Whatever the source, this noise must be filtered out. The design of the filter should provide for effective blocking of low frequency instrument noise and at the same time, provide for the widest possible band of heave periods. Clearly, the filter must be optimized for the particular instrumentation.

The filtering described above lies at the heart of the design of any heave instrument. This is particularly true if accurate heave corrections are desired in real time. The required filter must block all frequencies below the specific cut-off frequency and pass all higher heave frequencies undistorted. Undistorted, that is, in both amplitude and phase. An ideal filter is known, and its implementation in a digital computer is straightforward and easy. However, this particular filter cannot provide output in real time because it requires data both before and after the time of interest. In practice, use of this filter results in a delay of about 70 seconds in the output of computed heave. There are many less than ideal filters that can be implemented in real time; however, a penalty must be paid either in phase response, amplitude response, or in bandwidth.

In summary, two choices are available: approximate heave in real time with a reduced bandwidth; and error-free heave with maximal bandwidth but delayed in time by more than a minute. The Datawell prototype instrument provides both of these outputs.

FIELD TEST RESULTS

In June 1976 the A. D. Little and Datawell instruments were field tested onboard a 33-foot survey launch near the mouth of Chesapeake Bay. The launch was equipped with a Ross digital depth sounder and a digital data acquisition system. The tests were conducted over a smooth, flat bottom.

Figure 6 demonstrates the performance of the A. D. Little instrument. The launch was experiencing heave up to 9-feet peak-to-trough with a typical period of 5 seconds. Corrections for heave, roll, pitch, and sensor-transducer displacement were made for each digitized Ross depth for a 2-minute time span. Notice that the average of the uncorrected depths is 25.1 feet, while the average of the corrected depths is 24.7 feet. This 0.4-foot difference results from pointing errors that always give measured depths that are deeper than the true depths.

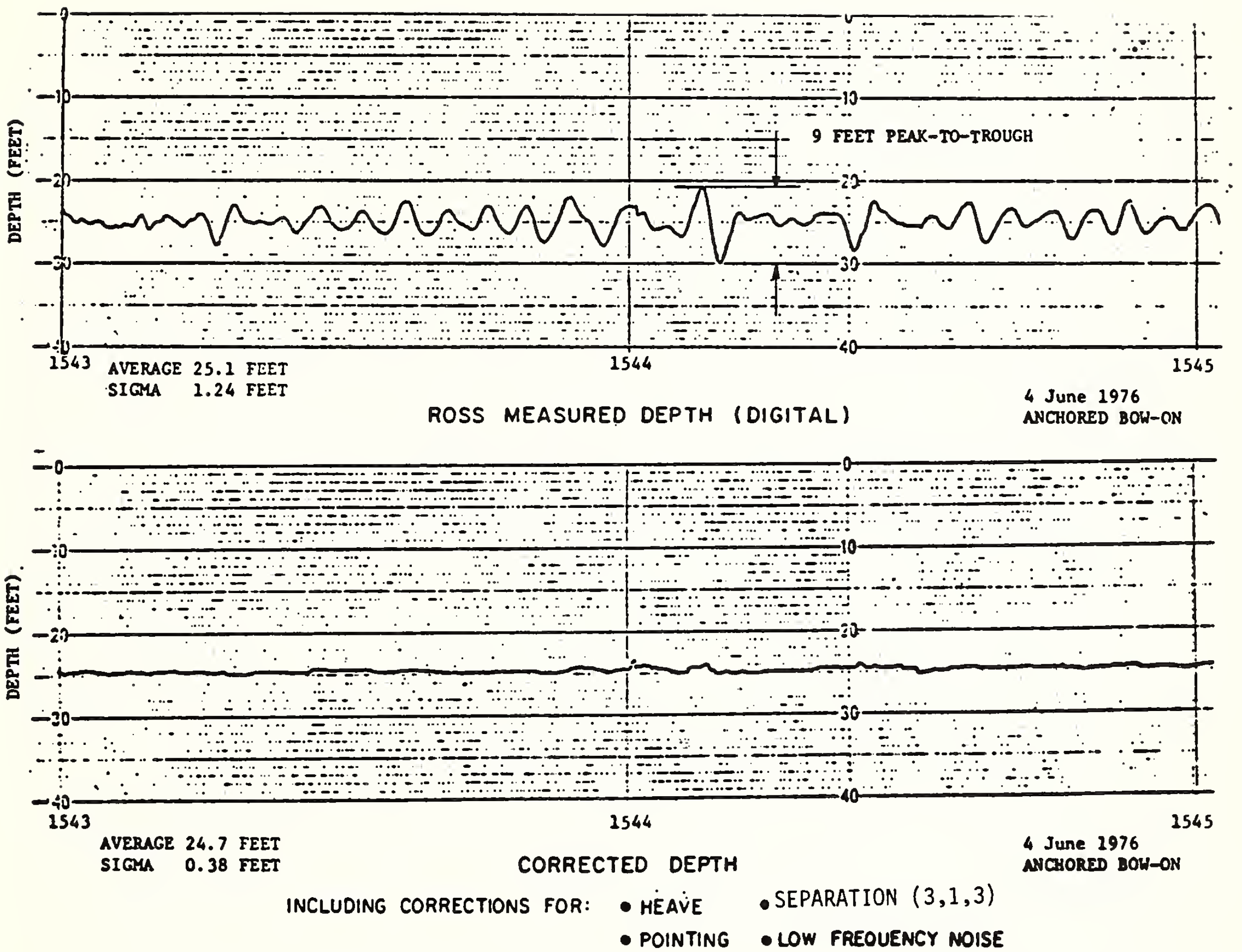
Figure 7 illustrates the performance of the Datawell instrument. The launch was running with the seas and experiencing a heave period of about 20 seconds. Figure 7B shows the result of correcting for 20-second period heave with a 15-second instrument bandwidth. This illustrates the condition where the launch was operated outside the operational envelope of the instrument. Figure 7C shows the results of making the correction with a 30-second instrument bandwidth. The spike appearing on all three of the plots is a Ross depth digitization error.

INSTALLATION CONSIDERATIONS

The location of the instrument on board the survey vessel can have an influence on its performance. The instrument should be located as near as possible to the center of vessel motion. The farther from this location, the more the instrument will experience unwanted centrifugal accelerations as the vessel rolls and pitches. These undesirable centrifugal accelerations will result in errors in heave, roll, and pitch.

CONCLUSION

The viability of both the Arthur D. Little and Datawell designs have been demonstrated in field tests. An operational instrument--HIPPY 120--has evolved from the Datawell development effort. It has been in service for over 2 years onboard the NOAA Ship DAVIDSON as part of the Bathymetric Swath Survey System (BS^3) a multi-beam swath survey system. HIPPY 120 provides real-time heave with a bandwidth of 15 seconds, and heave with a bandwidth of 30 seconds delayed in time by 70 seconds. Digital logging equipment with magnetic tape storage capability is required in order to make full use of the data available from the instrument. HIPPY 120, in conjunction with the data processing and logging capability of the BS^3, has completely solved the problem of motion errors in bathymetric and hydrographic surveys.



Results of A.D. Little

Figure 6.--Performance of A.D. Little, Inc. , instrument.

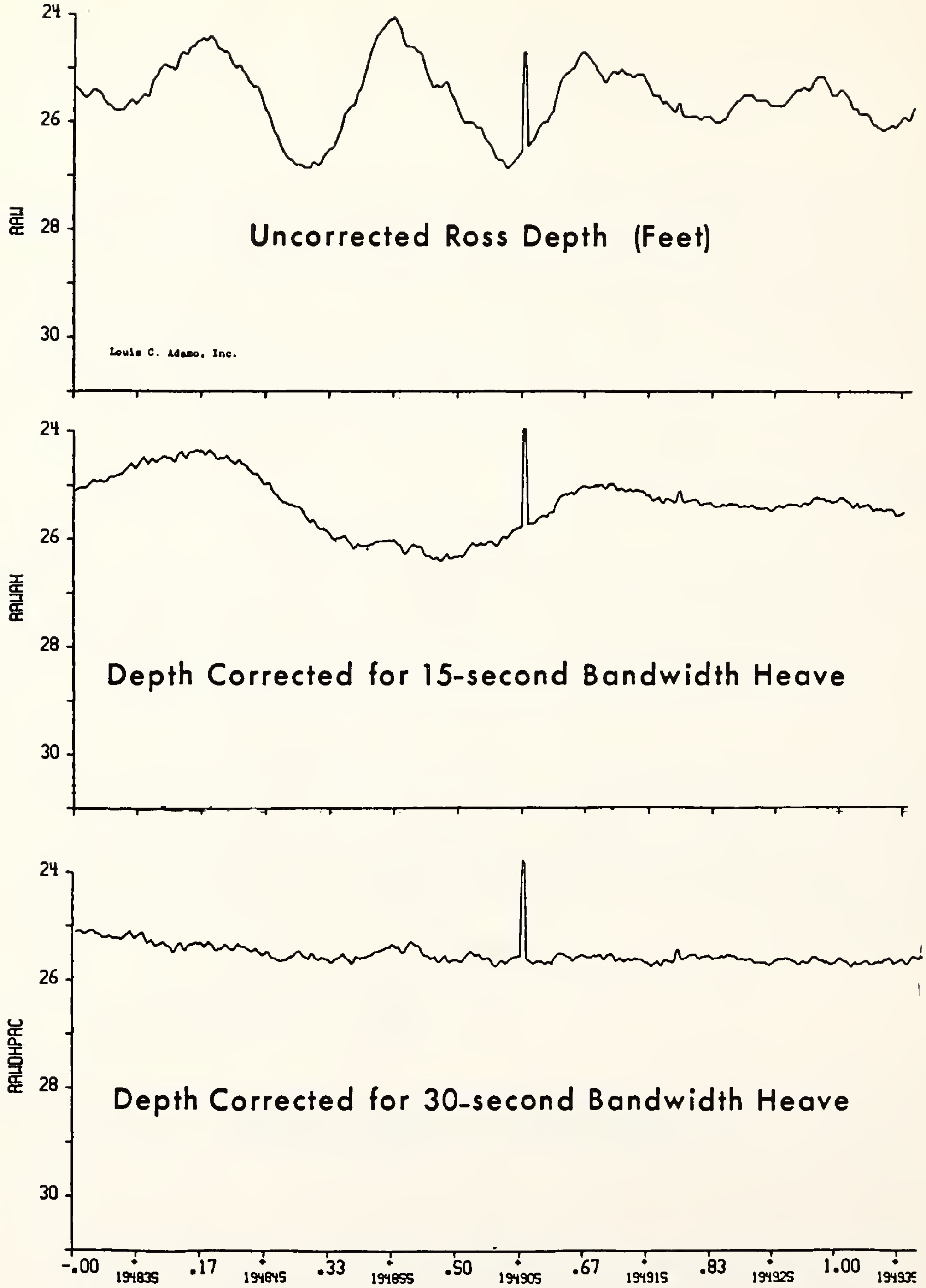


Figure 7.--Performance of Datawell instrument.

ACKNOWLEDGMENTS

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A STUDY OF FUTURE DEPTH RECORDER REQUIREMENTS

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ABSTRACT. A discussion of the needs and requirements of the National Ocean Survey with respect to future hydrographic survey depth recorders. A summary of the functional specifications recommended by the study team is also presented.

In April 1979, the Director of the National Ocean Survey (NOS) directed the establishment of an NOS study team to conduct investigations to determine the functional specifications for a replacement shallow water depth sounder.

The study team was formed with the following NOS members: Cdr. Fidel Smith and Charles Dinkel, Office of Fleet Operations; Dale Westbrook, Office of Marine Surveys and Maps; Dr. Lloyd Huff, Office of Marine Technology, as Chairman; Dr. Robert Embley, Director's Staff; and Philip Libraro, Office of Marine Technology, who joined the study team in August 1979.

The first four NOS members on the list made up an earlier study team for Admiral Powell to address the question of "What/Where is the bottom?" At the initial organizational meetings of the team, efforts were made to establish a philosophy for the study and a methodology for conducting it.

Somewhat in keeping with the recent popular "All you wanted to know about ________" books, the study team members each contributed lists of questions, the answers to which they felt were essential to anyone who wanted to specify a hydrographic survey depth sounder. These questions were condensed into basic topics which were divided among the study team members for investigation and resolution. The bulk of the team meetings were devoted to detailed discussion on the various topics as the members reported their findings, frustrations, and future direction. This framework proved to be highly successful. Individual members worked up certain issues for which they had the technical background and experience; they then presented the issue, discussed it, and strived to achieve a consensus from the entire study team. In this way positions, both pro and con, on the issues were discussed relative to the advantages, disadvantages, and general consequences or system impacts of espousing a particular recommendation.

Figure 1 shows the process in schematic form. The team developed salient questions and sought answers from a variety of sources, who responded quickly with value judgments, considered opinions, etc. Many NOS hydrographers responded to a questionnaire that was developed to obtain their input to the study.

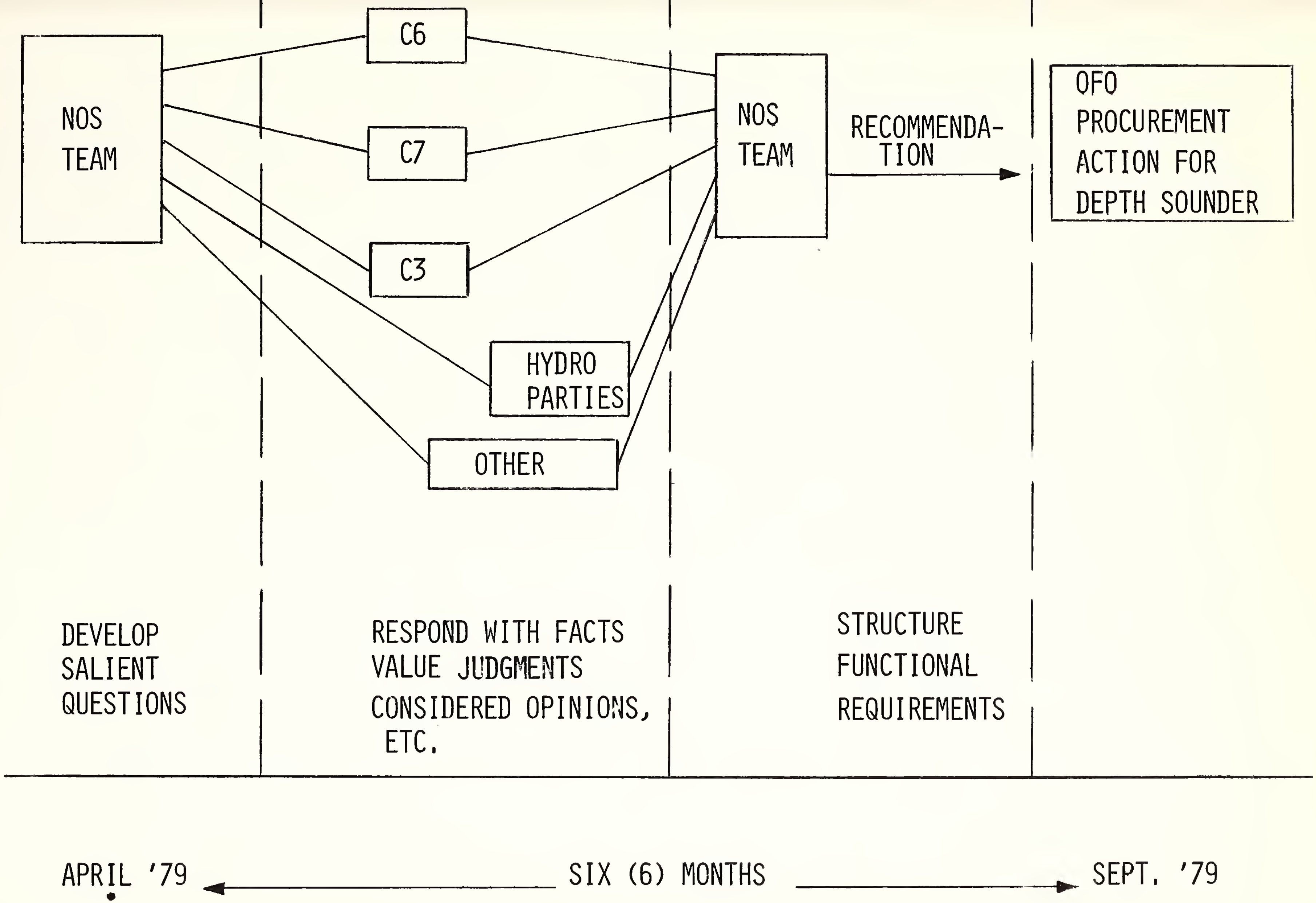

Figure 1.--Study team process schematic.

The NOAA Ship WHITING contributed to the study by assisting in the determination of acoustic noise characteristics of a Type 1 launch. The NOAA Ship RAINIER and the Naval Post Graduate School assisted by making available early results of the multiple beamwidth and multiple frequency tests which were reported the first day of this conference. Many individuals within NOS assisted by providing input and critical reviews on portions of the study report. I would like to express, for the team members, our appreciation of the interest and support which we have received during this effort and for the opportunity to make this presentation to the conference.

The study was scheduled for completion in September 1979; however, this date was not met. The complete report which documents and supports the recommendation is forthcoming within a short time following this conference.

One of the first topics to be discussed during the studies was "Why is a replacement necessary?" There were several factors which indicated a replacement may be necessary. Primary among these was the aged condition of the present systems, many of which were purchased 8 or more years ago. Another important topic addressed was "Why not just purchase a newer version of the Ross or Raytheon units which NOS is presently using?" To this question came the answer that there were multiple non-trivial reasons why NOS should strive for a system with operating and performance capabilities that could only be achieved with systems which had multiple frequencies and/or beamwidths.

NOS charting responsibilities, present and future, require improvement in present survey systems and techniques for acquiring and processing sounding data in support of changing uses for nautical charts, as well as scientific and engineering research and development.

NOS has established the need to modernize and update the coverage of their chart series. As a means of meeting these needs, NOS is introducing automated techniques in data handling, processing, compilation, and production in order to reduce the time interval between data acquisition and dissemination of new charts to the using public. The basic purpose of the shallow water depth sounder is to provide accurate data for use in both nautical charts and bathymetric maps. Nautical charts serve to instruct mariners as to the dangers to surface navigation, particularly within coastal waters. To construct nautical charts, the most shallow depths recorded by a depth sounder are emphasized to stress the navigational hazards. Bathymetric maps, however, are intended to instruct one in the physical shape of the bottom. To construct a bathymetric map, both the peaks and deeps recorded by a depth sounder must be given equal importance in representing bottom features.

The survey requirements on data for both these nautical and bathymetric purposes are closely allied with regard to shoaling features. In either instance, the field hydrographer should further develop an area, as prescribed by the hydrographic manual, when there are reasonable indications that shoal features might exist which have not yet been directly under the survey vessel. Regardless of whether a sounding represents a peak or deep, the accuracy, both vertical and horizontal, of the information supplied to a cartographer remains the same for the production of a bathymetric map.

Therefore, high resolution data which are appropriate for bathymetric mapping of an area also satisfy nautical charting needs. Higher resolution of the bottom acoustic return is one of the reasons why the hydrographic community has been moving toward greater and, in some cases, exclusive use of narrow-beam high frequency sounders. It achieves high resolution data through negative impact on survey efficiency.

It appears that NOS, having primarily emphasized that a sounder should accurately measure the depth of water directly beneath the transducer, may have reduced its capability to locate shoal features and items of relatively small cross-sectional areas such as rock pinnacles, wrecks, etc., in a reasonable amount of time.

Most narrow-beam echo sounders have one basic limitation in that they give no information on either side of the launch track line. This shortcoming, which may be significant in the proper development of an area, can be overcome by operating a broad-beam system in conjunction with the basic narrow-beam echo sounder. This allows for much greater information to be obtained about the bottom while obtaining a high resolution delineation of the bottom required by the hydrographer. In the proposed dual frequency depth sounder, additional potential information is obtained because the broad-beam transducer is also a lower frequency than the narrow-beam sounder.

Historically, depth sounder recorders were designed so that echoes from a sequence of transmission pulses could be conveniently correlated by a trained observer to obtain a rapid visual check on data confidence and to recognize any individual echoes that varied significantly from the normal, as well as patterns within the echoes that were characteristic of certain bottom features. This sort of subjective interpretation of echo information requires presentation of the total echo returns.

The amount of information one might glean from a fathogram depends on the size and shape of the footprints, pulse length, transmission frequency, and the resolving ability of the graphic recorder. There are several commonly observed features of bottom echoes. These include groups of echoes, each having the same length as the outgoing pulse, but with distinct arrival times, in which case part of the echoes might break into short crescent-shaped sequences. The crescent sequences are interpreted as being a series of echoes from highlights on the bottom. When an echo sequence breaks up into more or less well-defined crescent sequences followed by fainter patchy returns, a trained observer can estimate the roughness of the bottom. Higher roughness elements reveal themselves by more prolonged crescents. Reading fathograms for this extra information can provide a hydrographer in the field with the impetus to further develop an area around a track line that has shown reasonable indications of shoaling.

On the other end of the scale of information that can be gleaned from a fathogram lies a vast area related to deposits that are intermediate between muddy water and muddy seabeds and occur as a dense, soupy layer above the bed. This phenomenon is well known in harbors and ports that are located at the mouth of a river. The first echo return comes from the surface of the fluid mud followed by a stronger and longer echo return that comes from

underlying cohesive mud. In this instance, the character of the fathogram trace is heavily dependent on the frequency of acoustic transmission and the pulse length. Since the floating mud tends to have a featureless upper surface, the shape and size of the footprint are of little importance. Errors in true depth that occur from using this first echo might have been acceptable for nautical charts because they definitely cause mariners to exercise greater caution. The errors are, however, intolerable for bathymetric maps because the featureless top of the fluid mud masks the real features of the bottom.

A survey of sediment types over the 1980-84 primary survey areas in the Pacific, Atlantic, and Gulf coasts was conducted using the bottom type annotated on nautical charts and from published literature. It was found that there is a complete cross-section of bottom types in the 1980-84 priority survey areas, from sand-gravel bottoms to very low density mud and grass-covered areas. There are large, mud-covered areas where potential low-density layers exist on all three coasts. It was concluded that the replacement depth sounder required both high resolution capability and the presentation of total echo returns. The former is for use by an on-line computer or automatic data logger, and the latter is to preserve information that may be obtained from the fathogram by human scrutiny.

Two main system level constraints were considered during this study:

(1) the necessity of installation on a Type 1 Launch

(2) the interface requirements of the Hydro-Log system

A third important factor given consideration was the desire for operating a launch vessel heave measurement system in conjunction with the depth sounder.

With what was deemed to be proper consideration for the physics involved in acoustic depth sounding, the NOS operating environment, and the market availability, the team recommendation is being made for a depth sounder with the characteristics outlined in figures 2 through 6. The soundings will be made in units of meters with resolution of 0.01 meter and an accuracy $\leq$0.1 meter + 0.25 percent of measured depth.

The sounder will operate with eight scales as shown in figure 3. The specification for the performance is given in figure 4 as two probabilities: real detection and false detection. The system performance was evaluated under the assumption of bottom scattering. This is more conservative than the assumption of bottom reflection.

Figures 5 and 6 outline requirements to be placed on the recorder portion of the depth sounder. A digitized point record is to be a digitized dark line starting at the digitized depth value and extending down for 1 millimeter.

Figure 7 is a mock-up of a fathogram using mode 3 display showing a peak and a deep bottom feature. The figure shows those depths passed to the Hydro-Log as being marked by a line extending from the digitized point record through the heave record. The figure also shows position reference points being marked by a line extending across the entire graph and annotated with position control

- SIMULTANEOUS DUAL FREQUENCY OPERATION OF NARROW BEAM, HIGH FREQUENCY AND BROAD BEAM, MEDIUM FREQUENCY.

- ALL SOUNDINGS IN UNITS OF METER WITH A RESOLUTION OF 0.01 METER

MEDIUM	20-30 KHz	$30\text{-}45^{\circ}$;	-10DB BEAMWIDTH
HIGH	100 KHz	$7.5\text{-}10^{\circ}$,	-10DB BEAMWIDTH

Figure 2.--Major characteristics of proposed depth recorder.

SCALE NO.	DEPTH RANGE (METERS)	PULSE LENGTH MILLSEC	PULSE RATE PPM	AUTOMATIC CHART SPEED CM/MIN
1	0-20	0.12	600	16 CM/MIN
2	15-35	0.12	600	16 CM/MIN
3	30-50	0.12	600	16 CM/MIN
4	40-80	0.25	300	8 CM/MIN
5	70-110	0.25	300	8 CM/MIN
6	100-140	0.25	300	8 CM/MIN
7	120-200	0.50	150	4 CM/MIN
8	180-260	0.50	150	4 CM/MIN

Figure 3.--Depth recorder scale characteristics.

- PROBABILITY $\geq$ 0.95 OF DETECTING A BOTTOM WITH SCATTERING STRENGTH $\geq$-45 DB/M^2

- PROBABILITY $\leq$ 0.0001 OF MAKING A FALSE DIGITIZATION ON NOISE

BOTH OF THESE APPLY TO ALL RANGES $0.3 \leq R \leq 260$ METER UNDER BROAD BAND NOISE CONDITIONS AT THE TRANSDUCERS OF

100 DB RELATIVE TO 1 MICROPASCAL AT 1 METER IN A 1 Hz BAND AT THE MEDIUM FREQUENCY

80 DB RELATIVE TO 1 MICROPASCAL AT 1 METER IN A 1 Hz BAND AT THE HIGH FREQUENCY

Figure 4.--Performance specifications.

RECORDER

- LINEAR RECORDING ON DRY ELECTROSTATIC PAPER IN SEVEN (7) SHADES OF GREY
- LARGE SCALE RECORD
  0.1 METER DEPTH RANGE/MILLIMETER OF CHART SPAN (UP TO DEPTHS OF 50 METERS)
- SELF GENERATED CHART SCALES (41 LINES)
- AUTOMATIC ANNOTATION OF OPERATOR CONTROLS
- ANNOTATION OF CHART WITH POSITION NUMBERS
- FOUR DIFFERENT DISPLAY MODES

Figure 5.--Chart paper recording characteristics.

RECORDER

- THERE WILL BE FOUR DISPLAY MODES FOR THE DEPTH INFORMATION AS FOLLOWS:

  1. DIGITIZED POINT RECORD OF HIGH FREQUENCY ECHOES;
  2. DIGITIZED POINT RECORD OF MEDIUM FREQUENCY ECHOES;
  3. DIGITIZED POINT RECORD OF HIGH FREQUENCY ECHOES AND ANALOG PRESENTATION OF TOTAL ECHOES FOR MEDIUM FREQUENCY ECHOES;
  4. ANALOG PRESENTATION OF TOTAL ECHOES FOR MEDIUM FREQUENCY ECHOES.

- THE CHART WILL BE DIVIDED INTO TWO SECTIONS, ONE FOR DISPLAY/SOUNDING INFORMATION AND THE SECOND FOR DISPLAY OF OPERATING STATUS AND VESSEL HEAVE INFORMATION.

Figure 6.--Chart paper recording characteristics.

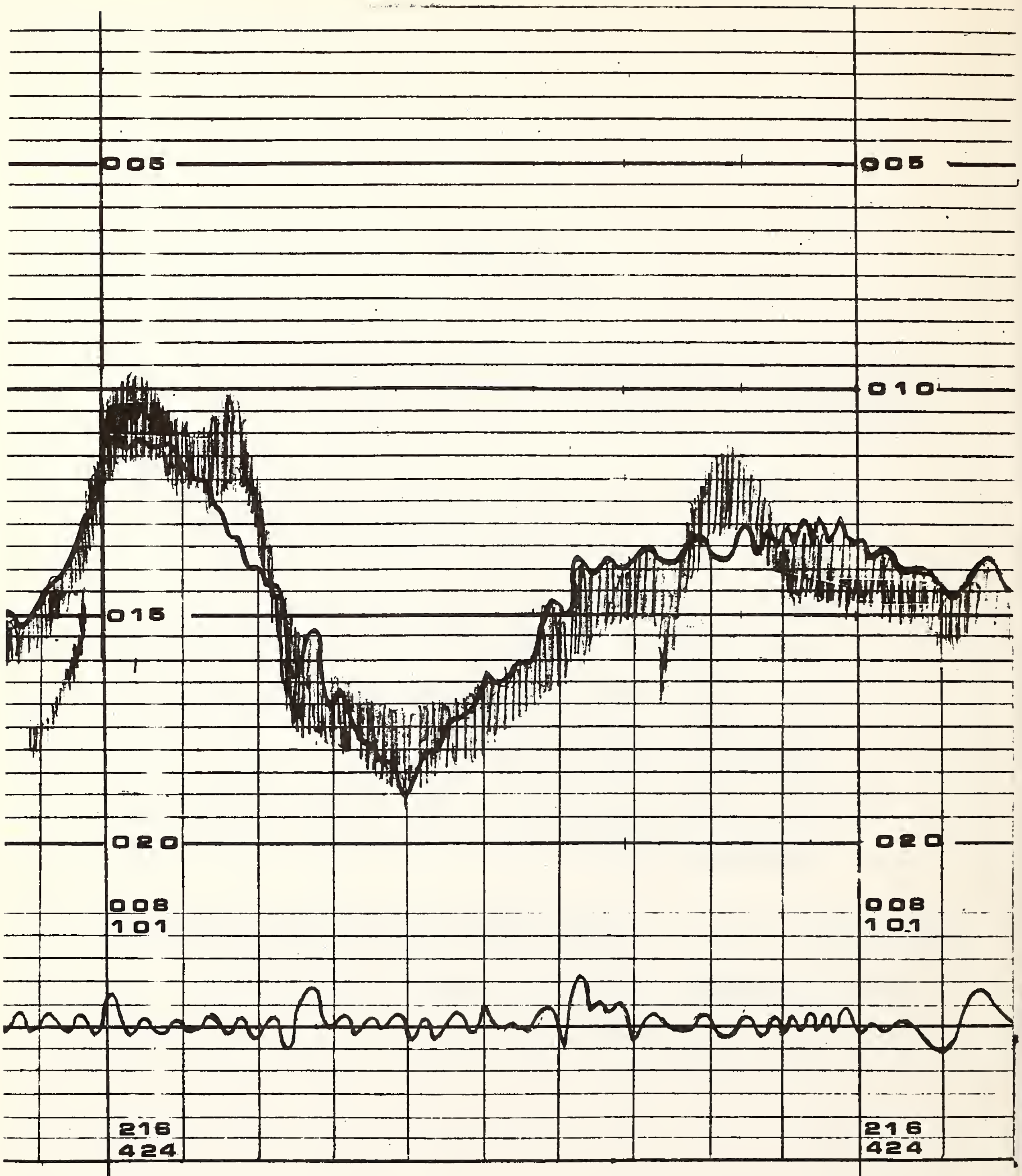

Figure 7.--Depth record mock-up.

numbers. The three-figure numbers shown at the upper and lower portion of the heave record scale indicate the status of operator controls. The heave scale would remain 0.1 meter/millimeter independent of the depth scale on which the sounder is working.

This presentation has been too brief to lay out all the features and rationales, but I would now be pleased to have your questions and/or comments on the ones which have been presented or others which the presentation might have raised for you.

DISCUSSION

Mr. Urchasko: In the final acceptance test after you procure the shallow water depth sounder, how do you plan to demonstrate that it will meet accuracy standards and perform exactly as you want it to on the various bottoms?

Dr. Huff: That's a very good question and it is a difficult one. First, the approach of specifying the system performance in terms of probabilities was taken because those probabilities of detection and false alarm can be ascertained in the laboratory by actual test. Second, those system performance probabilities have been obtained under very conservative assumptions, and those assumptions were arrived at several ways--including field tests, straightforward use of the sonar equations, and physics considerations.

Another thing is, by taking the specs for existing commercial systems, although their specifications tend to be vague and they most always shy away from specifying that it will work on this or that kind of bottom, we can then work back to determine what sort of probability of detections should be achievable.

After the sounder has gone through that sort of laboratory testing, I would then envision that one would go out and perform regular hydrography with it. I have to hedge a little bit and say that although there was an extensive market survey made, we didn't find any system that was exactly what we would recommend. So it still remains to be seen whether or not this procurement is approached as a developmental program with an RFP, in which case there would be developmental testing associated with it, or whether NOS would just buy the closest commercially available unit; in which case, I believe it should go through a test and evaluation phase.

Cdr. Nortrup: Just a quick question. With your revised scale system, I hope that you intend to incorporate an automatic scale change feature.

Dr. Huff: That is correct. The automatic scale change feature is there. Another question one might ask is, "Is there automatic phasing with change of scale?" You don't have to do automatic phasing in this instance because that's already been taken care of by the chart annotation feature.

The other thing about "changing the scales" is that the recommendation is for a change to metric scales. There is a complete change of scales when going metric. The eight depth scales have varying amounts of specified over-

lap, but we chose not to specify the scale change hierarchy, such as, exactly how they were to determine when to make the changeover from one scale to the other and whether it should be different if the scale change is to a deeper or shallower scale.

I might add, in this instance, that there was a period of time during our study when it looked as if we would specify the source level, the beamwidth, and the receive sensitivity, and many other specific features. It came to the point that we would have essentially designed the system. But then we backed off and tried to make the recommendation in such a manner that the makers of hydrographic survey sounding equipment could use their engineering abilities and particular capabilities to make their own tradeoffs on how the system was made, so long as it still meets our probabilities of detection and false alarm.

Lt. Anderson: This is a question I didn't do a very good job of answering the other day. How would you select the wide beamwidth?

Dr. Huff: Concerning beamwidth, there is a tradeoff between precision and coverage. We did look at the effect of pointing error for different beamwidths. Suppose you did a roll to an angle that was less than half the beamwidth, there still would be no pointing error. As long as you're rolling or pointing such that there is a portion of your main beam directly beneath you, then presumably over a flat bottom the first echo return is still the correct depth measurement.

We want to use the broad-beam low-frequency system to increase the probability of detecting a shoal or shoaling but that's not the only reason for going to a low frequency transducer. In those areas where kelp or other conditions forces one to use the low frequency soundings for the legal survey, having too broad a beamwidth could reduce the sounding accuracy. Also, design studies showed that as transducer beamwidth increases, the maximum allowable transmit source level which is below cavitation decreases while at the same time the amount of noise into the transducer increases. Therefore, broader beams can decrease the signal to noise ratio for the returned echoes and that eventually results in loss of precision.

Those points were part of the team's rationale for selecting beamwidths.

THE IMPLEMENTATION OF GOMADS, AN INTERACTIVE GRAPHICAL DISPLAY SYSTEM IN THE PRODUCTION OF NAUTICAL CHARTS

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ABSTRACT. The Canadian Hydrographic Service's first digitizing system for converting nautical charts and field sheets to digital form became operational in 1972. At the same time, a high quality optical drawing system was put into use, initially for drawing the borders and grids for chart production and then later for drawing the cartographic data as well. It was recognized that some kind of interactive editing system would be needed for manipulating the cartographic data to correct errors introduced during digitization and to allow the cartographer to add new data or to modify its presentation. The digitizing system provided limited editing capabilities that were adequate during the experimental phase, however, an easier more flexible system was needed before chart production using digital data became viable.

An investigation of commercially available interactive systems was done in 1974 but these systems were not suitable for cartographic applications and would not meet the requirements of the Canadian Hydrographic Service.

This, plus the availability of the necessary hardware, particularly the larger storage CRT, resulted in the in-house development of an Interactive Display System, GOMADS (an acronym for Graphical On-Line Manipulation and Display System) beginning in 1975. It was designed for editing digital data to produce a file that will meet cartographic standards and reproduction requirements. It was designed to perform compilation functions, such as the selection of data for the compilation of nautical charts. GOMADS is also useful to hydrographers for editing and correcting digital information acquired with automated survey systems.

DESCRIPTION OF THE CARTOGRAPHIC STATION

The current version of GOMADS is implemented on a PDP 11/34 central processing unit with 128k words of memory running under RSX11M operating system and with the following peripherals:

1. A TEKTRONIX 4014 storage CRT display. The data are displayed on the screen, and a joy stick is used to move a cursor around the screen, so that coordinate information can be entered into the computer.

2. DEC VT05, VT52, VT100, LA36 terminals that display alphanumeric information. For the user, the 4014/cursor/joy stick combination is used to communicate the "where" information to the system while the alphanumeric terminals are used to enter the "what" information.

3. Two DEC RK07 cartridge disk packs. One disk is used for software, and the other disk is used for data.

4. Two 9-track 800 bpi magnetic tape drives for data input and output.

5. A GRADICON digitizing table. It is difficult to find the exact position on the 4014 screen for adding information, so a cursor is used as an accurate pointer for the addition of data into GOMADS digital files directly from the chart which is laid on the table.

6. A CALCOMP-960 used as a fast verification plotter. It will create ink plots on paper from the GOMADS file.

7. A TEKTRONIX 4631 hard copy unit copies whatever is displayed on the 4014 screen when the copy switch is pressed.

A GERBER 32 flat bed plotter equipped with a PS-5 light head projector and controlled by a PDP 8 mini-computer produces high quality check and final film plots in positive form.

DESCRIPTION OF GOMADS

THE GOMADS System was designed to handle the following volume of digital data: 100,000 soundings; 5,000 inches of incremental lines; 1,000 symbols; 2,000 names; some point to point lines.

GOMADS allows for the manipulation of the above kinds of data in symbolized and unsymbolized form. An example of symbolized data would be a low water line that would be digitized as a solid line and output as a dotted line. If the low water line was being edited as a symbolized line, it could be changed by moving each dot separately. Data are usually edited in the unsymbolized form. When a plot of the GOMADS chart file is required, the data are symbolized through the STARS Program. Usually a program called MOSAIC is used to register a digital file in cartesian coordinates to the geographical origin and to generate crosses at specified locations for future

graphic registration purposes before editing with GOMADS begins. MOSAIC can also be used to change the scale and projection, to window, and to concatenate digital files.

The GOMADS editing system is based on a three-way computer-user dialogue between an alphanumeric terminal, the user, and a 4014. GOMADS instructs the user for each step of the editing process, so that a users' guide is not really necessary. GOMADS also requests that a verification be made for each change, thus helping to prevent hasty or careless moves.

For editing with GOMADS, a magnified portion of the digital file is drawn on the 4014 screen. The cursor and accurate pointer can then be used to delete, add to, change, or move the displayed line, point, numerical, and name data. GOMADS can also be used for sounding selection where some soundings can be flagged, and the remaining data can be kept in the background. GOMADS can be used to concatenate two or more digital files as in the case of information that overlaps with another chart or in adding a border.

THE IMPLEMENTATION OF GOMADS

Presently, the checked and approved compilation manuscript is digitized during the production of nautical charts. As mentioned earlier, imperfections and errors exist in the digitized data. Linework, for example, is not as pretty when digitized as when scribed manually. A program is used to smooth lines by removing jogs caused by grid size or vibrations, but it is not enough and some lines must be smoothed with GOMADS. A copy of the digitized data is produced and compared to the source. The discrepancies are marked on the check copy, and the digital file is corrected accordingly with GOMADS. The most common errors encountered are displaced lines, soundings, or symbols where the user digitized off position, wrong sounding values, features digitized more than once, lines not joined or overlapping, and features not digitized.

The incorporation of the border into the chart data file is also accomplished with GOMADS. Border breaks are made with the GOMADS line segment delete command. Negatives are made for printing the chart in colour overlays. It is desirable to have the smallest possible number of overlays. It is an advantage, therefore, to have the border concatenated to the digital chart file via GOMADS so that the border can be plotted with the rest of the black information, resulting in one black overlay. Once editing of a file is presumed to be complete, a combined film plot of all the data is produced. The plot is checked. If more discrepancies are evident, the GOMADS file is further edited. When the cartographer is satisfied that the editing is finally complete, the chart is plotted in overlays, one overlay for each colour on the chart. The data needed for the colour separation would also be plotted on film.

Insets can be concatenated to chart files with GOMADS. Overlapping information from other charts can also be concatenated. This would involve further editing of the digital information. Overlapping material would have

to be deleted and clipped, and lines that did not quite meet would have to be joined. With GOMADS, field documents could also be concatenated for compilation purposes.

GOMADS can be used by hydrographers for sounding selection and contour development. It can also be used for making corrections to sounding values as in the case of a datum change.

Chart 8015 was chosen as a project to simulate the compilation of a hydrographic chart. Field information was digitized and then concatenated with GOMADS. The digitized information was overselected so that compilation changes and decisions could be made at the GOMADS editing stage. The selection of data and the development of contours were then made on the screen. The main compilation process was deleting the data from the digitized hydrographic file that was not required for the final chart presentation. Overlapping material also had to be deleted, and joins were made to linework that did not meet. With the exception of names, notes, the title, and some aids, no manual drafting was involved in the construction of Chart 8015. This project showed that it is possible to compile charts interactively with GOMADS.

The digitizing and editing of nautical chart information can be introduced at different stages of the chart construction process. Once data are digitized, however, it should then be edited. For the past 2 to 3 years, the Canadian Hydrographic Service has digitized the compiled checked chart manuscript. It was decided that this was the best way to evaluate the GOMADS system because there were already several charts in production at the compilation stage. Some testing has been done, and it is felt that digitizing and data manipulation with GOMADS can start at an earlier stage in the chart production process.

CONCLUSION

The GOMADS interactive graphical display system has been used in the production of nautical charts since 1976. During the past 3 years some modifications have been made to the system. An example is the inclusion of the GRADICON digitizing table in the editing station which is used for the addition of data into GOMADS digital files directly from the chart which is laid on the table. Now that experience has been gained in using GOMADS, the great potential of the interactive editing system can be realized. The use of GOMADS has to this time been limited mostly to the editing of data digitized from the compilation manuscript. GOMADS will only become efficient for the interactive compilation of charts when more hydrographic data are collected in digital form. GOMADS can also be used for updating digital chart files for new editions. Presently it is felt that it would be relatively easy to keep digital files updated so that when a requirement for new editions arises, new plots can be generated. Digital data could be used for the concatenation of overlapping charts or be reduced to produce smaller scale charts with the aim of helping to reduce chart production time.

By using and testing the GOMADS interactive graphical display system suggestions for its future development, to make it more convenient, and to

perform more functions, can be discovered. Improvements in software could include the development of new commands, multifiles for compartment charts, and the ability to display symbolized and unsymbolized information at the same time for a comparison of the two. Another impact on the future of the GOMADS interactive display system would be in the area of new hardware. A multi-coloured display could be useful for the digital compilation of data. Different types of information could be displayed in different colours, thus representing the different chart overlays and better simulating the look of the final product. Colours could be very useful for making a distinction between source information and selected information. The use of larger screens would have to be carefully evaluated. The cartographer would like to have the picture at a scale of 1 to 1 or chart scale. This is too small for editing, however, where a scale of 4 to 1 would be more manageable. The ideal might be to have two screens in the GOMADS cartographic work station. One screen could be used to display the complete chart, and the other smaller screen could be used for editing. The smaller screen would be less awkward for editing because the cartographer would not have to reach so far.

With future enhancements, experience, and testing, GOMADS will become an even more useful and powerful tool.

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NATIONAL OCEAN SURVEY AUTOMATED INFORMATION SYSTEM

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ABSTRACT. The National Ocean Survey is automating the processes required to create and maintain nautical charts. Automated techniques have been introduced in three basic areas: data management, interactive graphics, and management reporting. The National Ocean Survey Automated Information System (NOS/AIS) uses some of the latest advancements in data processing to perform these functions. An online geographically oriented data base coupled with an array of interactive graphics systems enables cartographers to maintain up-to-date charts.

INTRODUCTION

One of the primary missions of the National Ocean Survey (NOS) is the production and maintenance of nautical charts for the navigable waters of the United States and its possessions. This is a continuous effort due to the constant changes caused by natural and human processes. To measure these changes, NOAA has a fleet of ships and aircraft gathering data for charting purposes. Information is also received from other U.S. Government agencies and the private sector. The current base of charting information must be updated to reflect any potential dangers to navigation that are uncovered by the new data.

In theory, new data are collected in the field, and charts are modified to reflect the changes. In practice, however, bottlenecks have developed. Sophisticated data collection techniques using computers, rapid navigation, and digital fathometers have outpaced the ability of the cartographer to use all of the new information. As the volume of data increased, NOS found itself in the position of applying only the critical adjustments to charts while the rest of the data were stored for future use.

To alleviate this problem NOS has developed a set of computer-based systems that will speed the application of data to nautical charts. These include:

- Automated data acquisition systems aboard NOAA ships that also accomplish some preprocessing functions.

- Automated processing facilities at the Atlantic and Pacific Marine Centers for verification of data before they are sent to NOS Headquarters.

- A digitizing system to capture graphic information in digital form.

- Flatbed scribe plotters and a laser raster drum plotter to produce negatives for chart printing.

The missing link in this automated chain of processes has been recently developed under contract by the Planning Research Corporation. This system, the National Ocean Survey Automated Information System (NOS/AIS), receives data from the Marine Centers, the digitizing subsystem, and outside sources. It stores these data in a readily accessible form and allows retrieval for interactive compilation of charts. The system also produces digital output which can be plotted for use in chart reproduction. Figure 1 shows the relationship of the AIS to other computer-based systems in NOS.

NOS/AIS

NOS/AIS is the backbone of the NOS effort to automate nautical charts. It performs three critical functions that are necessary for chart construction and maintenance. First, it provides a mechanism for managing the vast amounts of data that are required to create and maintain a complete chart product. Second, it provides the cartographer with a tool that allows the interactive manipulation of cartographic information. Third, it provides the management information necessary to control the charting process. The AIS not only handles these basic functions, it also performs them in a timely manner. An explanation will now be given on how the AIS fulfills these requirements.

Data Management

NOS is responsible for charting approximately 2 million square miles of the Earth's surface. The amount of data necessary to represent this area is immense and, therefore, requires effective management. Automated data processing provides this tool in the form of an online data base.

In a data base environment all data relevant to an organization's tasks are stored in a central repository. Access to this data is controlled by a sophisticated set of computer software called a data base management system (DBMS).

The way the data are organized within a data base is very important to the successful operation of the system. An organization must analyze how its data are used and structure the data base accordingly. NOS examined two different approaches to data base organization. The first was based on a chart oriented data base. Since the ultimate output of the system is a chart, it seemed logical to organize the data base by chart product. The same cartographic feature will likely appear on multiple charts, however, due to the hierarchy of scales and overlapping coverage. Therefore, in a chart oriented data base, the same feature would be stored once for each chart on which it appeared. This redundant storage of data would greatly increase the size of the data base. It would also require each chart representation of a feature to be modified when a change occurred.

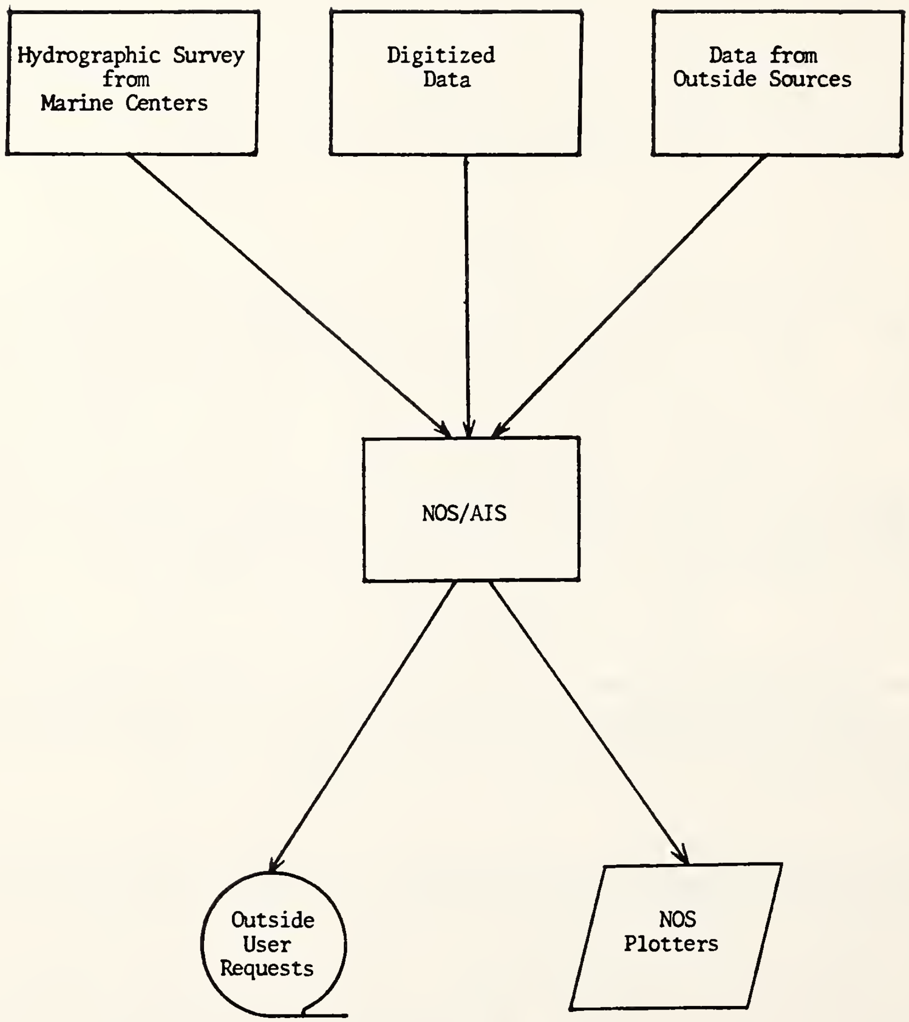

Figure 1.--Relationship of the AIS to other computer-based systems in NOS.

An alternative scheme for organizing the data base solved these problems. By using a geographically oriented data base each feature is stored only once. Accompanying information is used to tell how the data are depicted on the various charts. This technique eliminates redundant storage, which in turn, decreases the size of the data base and prevents conflicting depictions of features within a set of charts.

In this structure a feature is stored according to its geographic position. To make the storage scheme more manageable, the Earth's surface is subdivided into 1-degree by 1-degree squares. Certain types of data that fall within a given degree block are stored together:

- Published traveling features and channels. These features typically extend distances greater than 5 minutes, and they are currently published on at least one chart. Examples are pipelines, cables, and channels.

- Unpublished traveling features and channels. These are the same as above except that they are not currently published on any chart.

- Small scale topographic data. These are published and unpublished topographic data that may appear on charts of smaller scale than 1:100,000.

The data base management system used in the NOS/AIS is named TOTAL. This DBMS allows direct access to master records on disk storage devices. Direct access is important because it is the fastest way to retrieve information from a computer system. Each degree block is defined as a master record to the TOTAL data management system. This allows rapid access to the above types of information.

Near the shoreline, where data are more heavily congested, a further refinement is made to the degree block subdivisions. In these areas a master record represents an area that is 5-minutes by 5-minutes square. These types of data are stored within each of these blocks:

- Large scale published features. These are features that are published on charts of scale larger than 1:100,000 and are not traveling features or channels.

- Small scale published features. This category contains published features that appear on small scale charts, excluding traveling features and channels. If a feature appears on both small and large scale charts, it is grouped with the small scale data.

- Unpublished features. This group contains all unpublished features, except traveling features, channels, and small scale topographic data.

A variety of data records have been devised to represent the different types of cartographic features. Usually a group of these records is required to represent one feature. A shipwreck for example, requires four records to be stored. The first record, called the base data record, holds information about the type of feature and its geographic position. The second record in the sequence, called the compilation fact, tells which chart entities the

feature appears on. The next record describes the position, characteristics, and publication status of any nomenclature that accompanies the symbol. The last record in the sequence gives the actual text which appears on the chart, for example, "SUBMERGED WRECK."

That basically describes how the data are organized. Data are to be loaded into the data base in phases. The first area to be loaded, the Gulf of Mexico, will be completed by early 1980. Since all of the data for a given area is loaded at the same time, cartographers will be able to use the system's full capabilities just as soon as an area is loaded. Other areas will follow the Gulf as the data collection effort is completed, and the entire 3 billion character data base will be loaded by 1983.

AIS Hardware

To store and access 3 billion characters of data require a sophisticated computer system. Figure 2 is a diagram of the NOS/AIS hardware configuration.

The central site portion of the system consists of two Univac V76 minicomputers in a master and slave configuration. The data are stored on disk storage units with a 300 million character capacity. There are three high speed tape drives attached to each central site minicomputer. These are used to input new data to the system, to output data to the NOS plotters, and for other system functions. The central site is attached to the cartographic work stations by a high speed data link. The work stations will be described in detail later.

AIS Software

Having now seen how the data are organized and the hardware components that are available, it would be beneficial to start a cartographic request through the system to see how everything works. This will also provide an opportunity to describe the computer software that controls the system.

A cartographer initiates the process by submitting a request for data to be sent to one of the cartographic work stations. The request may take many forms. The most frequent requests are for data that lie within a given geographic area or on a given chart. The area can be any polygon with from three to eight sides. Chart and area requests can be qualified to limit unwanted data from being sent to the work station in numerous ways. For example, one can request only published data, only unpublished data, or only a certain type of data like soundings or buoys. The request must also include control type information, for example, a user number for security purposes, a request number, and the number of the work station to which the data are to be sent.

A typical example of a cartographer's use of the system is to apply the information supplied by a new hydrographic survey to the appropriate charts. When a new survey is received at NOS Headquarters, it is loaded into the AIS "new data holding file." A cartographer then submits a request for the published data covering an area slightly larger than the survey to be retrieved from the data base.

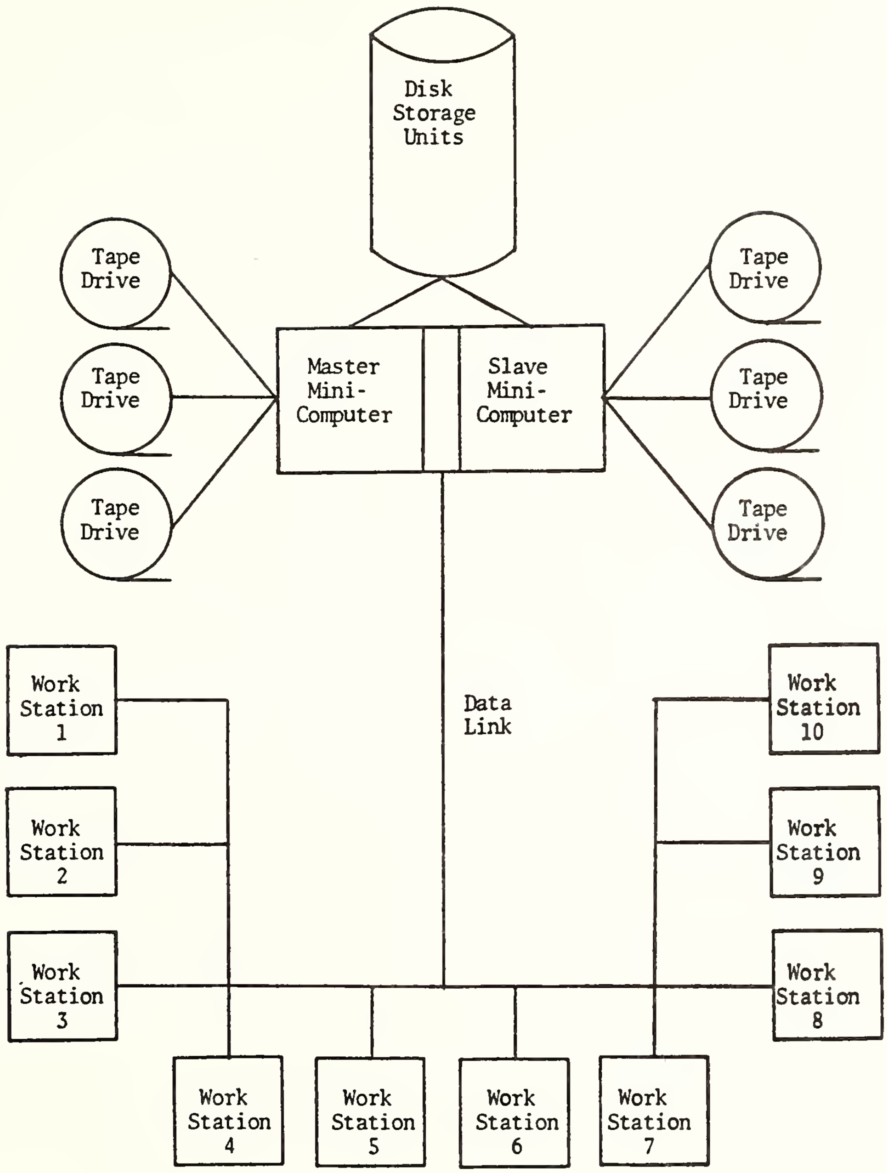

Figure 2.--NOS/AIS hardware configuration.

Once the request is submitted, an executive control program schedules the various programs that are needed without operator intervention. The first program edits the request for errors. The next program checks that all of the resources needed by the request are available, that is, that the data requested from the data base are not currently being used by another cartographer. To preserve integrity in the data base, two requests cannot use the same data at the same time. If all resources are available, the retrieval program then extracts the requested data from the data base and the new data holding file and sends them over the high speed data link to the work station.

When the data arrives at the work station, the cartographer may begin the work session. The activities at the work station are a part of the second function of the AIS, interactive graphics, and will be discussed in the next section of the paper. After the cartographer has finished with the data at the work station, the new and edited data are sent back to the central site to update the data base. The update program modifies the data base records that were edited at the work station, adds records that were introduced, and archives records that are no longer applicable. Records that are archived from the on-line data base are written to magnetic tape for long-term storage.

The last step of the AIS data management function is to back up those portions of the data base which were modified by the work station edit. All cell blocks that underwent changes are copied to magnetic tape. These tape copies along with a backup copy of the whole data base on disk will allow recovery from a failure of the online data base.

INTERACTIVE GRAPHICS

The second major function of the NOS/AIS is to enable cartographers to use data in a graphic form. Cartographic users do not really care about data base management systems or retrieval and update programs. What they do care about is the chart's graphic image. The user wants to see cartographic symbols, shoreline, and soundings the way they are represented on the chart. He or she is not particularly interested in strings of data base records.

To provide the transition from strings of records to a usable graphic display, the AIS has incorporated the latest techniques in interactive graphics. Figure 3 shows the work station hardware that provides this power. At this point it should be pointed out that only 2 of the full complement of 10 work stations have been installed. Experience gained from the use of these prototype work stations will play an important part in the selection of the next eight.

The current work station configuration contains the following hardware:

- One Univac V76 minicomputer to control work station processing
- Two disk storage units to hold work files and programs
- One Bendix digitizing table for cartographic reference and input

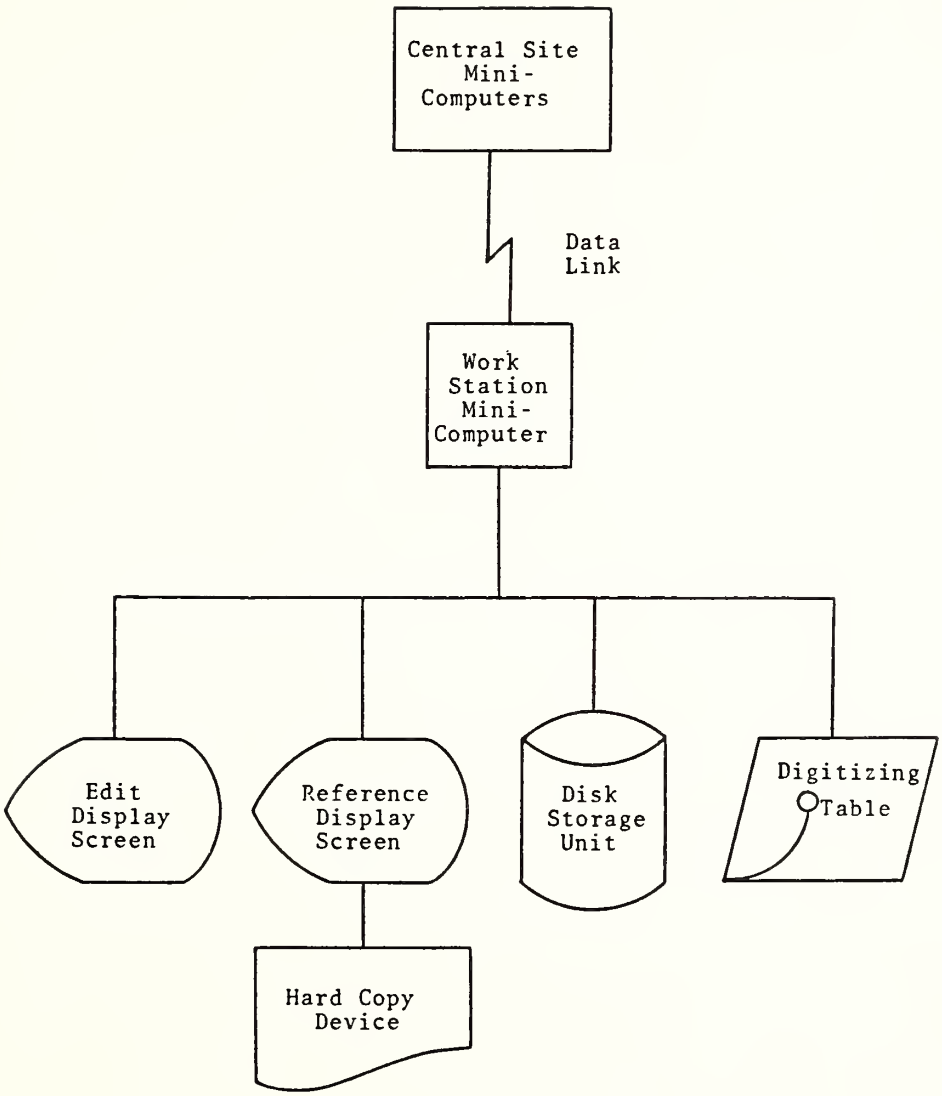

Figure 3.--Work station hardware.

- One refresh color graphics display screen for edit

- One graphics display screen for reference

- One hard copy device

These hardware components plus a large group of computer programs allow the cartographer to perform many cartographic functions.

To illustrate some of these functions, the hydrographic survey example that was introduced earlier will be continued. The example was left with the cartographic request, including the new survey, having been sent across the data link to the work station. The TOTAL data base management system is used at the work station to control access to the work file.

The cartographer has a scheduled time to use a work station. This time was chosen by the cartographer when the request was initiated. At the pre-established time using the appropriate employee number and security identifier the cartographer will attempt to sign on the system. Unauthorized access, based on these numbers, will cause the work station to disallow further actions, and a message will be sent to the central site operator.

Upon completion of a successful "sign on," the cartographer will place the largest scale chart to which the survey will be applied on the digitizing table. This will be used as a reference to the graphic displayed on the edit screen. The cartographer then selects the area of the chart that will be edited first. Data from the data base that are currently published on the registered chart will be displayed on the screen in the color green. (The screen can display five colors.) The cartographer will also ask to see pre-selected data from the new hydrographic survey. These are the new survey data that have been run through an automated sounding selection program. This program selects soundings that are critical to navigation and removes cluttered soundings so that an appealing graphic representation is given on a chart. These soundings are displayed on the screen in orange. If the cartographer wishes, the entire survey can also be displayed.

The cartographer then applies the soundings from the survey by publishing the appropriate ones. This is done by selecting a sounding on the screen by positioning a cursor under the displayed symbol. When a sounding is found it will blink on the screen. The "publish" button on a keyboard is depressed and the status of that sounding is changed accordingly. In the same manner, soundings from the data base may be changed to an unpublished status for the registered chart.

The survey is applied to the whole chart, and then the next smallest scale chart is registered on the digitizing table. The cartographer now asks for selected soundings. These appear in red and are those that were published on the larger scale chart. Since the level of detail at the larger scale is greater than at the smaller, only those soundings selected at the large scale will be applicable. This process will continue until the survey has been applied to all appropriate charts at the various scales.

The concept of applying data "through the scales" is a great benefit provided by the AIS. In the past, <u>all</u> new data were used at each scale. With the AIS a refined subset is used for each successive scale. This provides a great time savings.

When the cartographer is finished editing the data a sign-off command is issued. Before the data are sent back to the central site for update the transactions must be checked by an authorized reviewer. The reviewer signs on the work station with a special security identifier. If the chart has been incorrectly compiled, the reviewer may modify the data or have the cartographer sign back on to do so. When the chart is correct, the reviewer signs off for update. The data are then sent back to the central data base for update, as described earlier.

The application of a hydrographic survey is just one example of how the AIS aids in chart compilation. Channels, shoreline, or any cartographic feature can be added or modified in the same way. A very real benefit is gained by using the AIS to continually maintain charts. Continual maintenance means that when a change to a chart is received at NOS it is immediately applied to the existing base of chart data. In this way, a chart is ready for publication with the most current data at all times.

When a new edition of a chart is to be issued a cartographer will make a request for a chart retrieval to the AIS. The chart will be sent to the work station and the cartographer can manipulate the data to improve the chart's appearance. This might include the rotation of cartographic symbols, repositioning nomenclature, or clearing an area for text. Rotation is accomplished by finding the desired feature and depressing the rotate button until the desired angle is reached. Repositioning of features is handled by using four function buttons which move the feature up, down, left, and right. To blank an area of shoreline the two points on the line that bound the area are found and unpublished.

With this type of interactive capability the AIS has removed the need for a cartographer to spend time drafting. With manual techniques the cartographer must draw in all of the changes. With the AIS these functions are performed by pushing a button. The cartographer's major effort is in applying cartographic skills, not drafting.

One final example of the power of the AIS must be cited before going on, and that is the creation of a new chart. In this example assume that a smaller scale chart is being created. The cartographer will first add the geographic limits of the chart to the chart information file. Then an area retrieval will be made that encompasses the new chart. When the data arrive at the work station the cartographer will display the data for the larger scale chart and designate it as "selected." This means that the data will be applied to another chart. The system will ask the cartographer what chart is to be the compilation chart, that is, the one to which the selected data will be applied. The cartographer enters the number of the new chart and then proceeds to publish the appropriate data from the selected chart to the compilation, or new, chart. This technique provides considerable time savings over the manual creation of new charts.

Management Reports

The final function of the NOS/AIS is to provide management with sufficient information to aid in scheduling, controlling costs, and evaluating the system's performance. Information-gathering modules have been incorporated in the AIS software to supply input to the management reporting function. Some reports are available to cartographic management:

- Chart job accounting. This report gives the work station time, system time (retrieval and update), the number of transactions, and the cost incurred based on cartographer and reviewer time. The report can be generated for each chart.

- Geographic area job accounting. NOS cartographic staff is subdivided into seven teams, each responsible for a geographic area. This report gives time, transactions, and cost information as above, except that it is based on a whole area rather than one chart.

- Reviewer job accounting. This gives the same information keyed to a reviewer.

- Outside user job accounting. This gives the same information keyed to a request outside of NOS.

- Cartographer job accounting. This gives the same information on a given cartographer.

- Work station usage. This gives the time the work station was active, number of transactions, and various file sizes of a given work station.

- Data base access. This reports the frequency and types of data accessed, number of transactions, and area of data base access.

- New document status. This tells which new documents fall on a given chart.

- Chart status. This reports which charts fall on a given new document. The last two reports are used to help schedule work.

- Chart history. This report tells what new documents have been applied to a chart.

In addition to the above, many other reports supply information to systems programers and the Data Base Manager. All of the reports can be generated on an "as needed" basis.

CONCLUSION

NOS is one of the world's leaders in the advancing technology of automated cartography. The NOS/AIS was a pioneering effort in this field, and, as a consequence, many lessons had to be learned along the way. The most valuable

information was gained once the system was in place and cartographers started using it. NOS will put this knowledge to use when the next eight work stations are procured. But this will not end the evaluation process that analyzes user needs and implements appropriate solutions. Technology is advancing at a tremendous rate. But the technical advancements are only good if they are put to use. NOS will stay abreast of technology to give its cartographers the tools they need to cope with our dynamic environment.

DISCUSSION

Lt. Cdr. Bass: If you have very specific questions, you can see me during the lunch break or during the tour this afternoon. Any questions?

Cdr. Richards: You've explained how a cartographer might use AIS. How would you envision a hydrographer using the automated information system?

Lt. Cdr. Bass: The primary application for AIS is the updating of nautical charts. We have secondary uses, namely, outside users and other NOS users. A hydrographer can request all charted data to be sent to him on a magnetic tape, and, as the Hydroplot System evolves, he'll be able to plot it right on his ship, at any scale he wishes.

The hydrographer can pull any data out of the data base, such as shoreline, fixed, and floating aids. Data with low quality codes would be candidates for presurvey review items and could be pulled out. The hydrographer can get a magnetic tape of any particular subset of our data base that he wants. John?

Mr. Perrow: Greg, one thing I didn't quite pull out of it was, what happens to the obsolete and the superseded data, such as historic shorelines and things which I know are going to be involved in litigation. Do you have any means of storing this outdated material?

Lt. Cdr. Bass: Data that are superseded by new data are identified as such, and will be stored on magnetic tape in our tape library. In response to any future litigation, we can pull this data back out of the tape library, display it on the screen, or make a tape of the new data and current data, to be plotted on Marine Charts' plotters. Thus, the data are never lost; it's just put on magnetic tape as an archival medium. Yes?

Lt. Anderson: Are your cartographers going to need a degree in computer science to run this thing?

Lt. Cdr. Bass: Although the two current work stations are rather cumbersome, we are developing a user-oriented manual to make it easier. For future work stations, a menu selection system will allow the user to interact with it without much memorizing. No, a great degree of specialized training is not required.

No other questions? Thank you.

RELIABLE BENCH MARKS

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ABSTRACT. Technological advances in survey observations have outpaced the development of more reliable monumentation, i.e., more stable and long-lived bench marks. Movement caused by natural phenomena or by people can make monuments positioned according to various survey specifications less accurate than the precision of the survey would indicate. Movement originating deep within the Earth is difficult to avoid, but tends to be small in magnitude. Natural movements originating near the surface are of greater concern because they are restricted horizontally, and thus are amplified vertically. Frost heave, shrinking and swelling of expansive clays, settlement, and damage from people can be counteracted or avoided with the use of properly selected bench mark designs and thoughtful site selection.

INTRODUCTION

Terminology

Laymen often use the term "bench mark" (or BM) in a general sense to denote any type of survey control point. To be technically correct, a bench mark is a point used specifically as a reference for elevation. Its horizontal position may be determined incidentally, but the essence of a bench mark is its established vertical distance above or below an adopted datum. A "permanent bench mark" is intended to maintain its elevation without change for a relatively long time. A "temporary bench mark" is not expected to last as long.

In the National Ocean Survey (NOS), bench marks are set primarily for two reasons: to provide a National Network of Vertical Control, used as a framework for referencing other elevations; and to provide relatively stable points on land to which local mean sea level at tide stations can be referenced. Bench marks used for the second purpose are called "tidal bench marks," and may or may not be connected to the National Net.

Scope

This paper explains how to set permanent bench marks that will remain relatively stable for a long time. It is written for the hydrographer, and thus is geared primarily toward the setting of tidal bench marks. First, focus is directed toward factors that contribute to bench mark movement and destruction. Then, methods of avoiding or counteracting these problems are discussed.

Why Such Accuracy?

A reasonable question is, "Why take such care in establishing stable bench marks when water level readings are so imprecise in comparison?" There are three reasons. First, although the individual water level readings may not be very precise, over a period of time the averages give quite accurate results because of the great number of readings taken. Second, to remove as much uncertainty as possible from the connection of sea level to land, there must be as little movement as possible between bench marks for the duration of the observations. And third, if the tidal bench marks are connected to the National Network at a later date, they should not have changed in elevation, or the connection of sea level to the Net will be in error by the amount the bench marks moved.

SOURCES OF GROUND MOVEMENT

Deep Movements

Vertical displacement on the surface of the Earth is the result of a conglomeration of movements occurring below the surface. Starting with those of deepest origin, there is deformation of the Earth's crust due to convection currents within the mantle, isostasy, tectonic motion, the swelling of magma pockets, subsidence from the pumping of oil and water, rebound over previously glaciated areas, subsidence over underground mines and caves, and consolidation of sediments. These movements illustrate the complexity of the bench mark stability problem on an absolute basis. They are difficult or impossible to avoid or counteract. Fortunately, they are usually of small magnitude and uniformly affect large areas of the surface. Here, bench mark stability shall be based on relative movement between marks rather than on an absolute basis. Therefore these movements are of no further concern.

Frost Heave

Of greater concern are movements originating near the surface. These are greater in magnitude, but also easier to avoid or counteract as explained later in this paper. Frost heave is a commonly known near-surface ground movement. The amplitude of frost heave depends on weather, soil type, and availability of water. It occurs in rather localized spots within areas of frozen ground. Frost will heave the ground as much as 15 or 20 centimeters. The effect of frost heave on a bench mark can be even more drastic because

subsequent settlement of the mark after the ground thaws is usually not as great as the upheaval caused by the frost. After a number of seasons the mark can be jacked entirely out of the ground.

Shrink/Swell

Another near-surface movement is the shrinking and swelling of what are called "expansive soils." Certain clays, due to their crystalline structure, will swell when water is added and shrink when water is extracted. Because a soil mass is for the most part restrained from volume change in the horizontal plane, most of the movement takes place vertically. Some horizontal change also takes place, however, as evidenced in a dried-out clay soil mass where a geometrical array of cracks can be seen on the surface.

The amount of volume change depends partially upon the amount of water added to or taken from the clay. Expansive clays that maintain a uniform moisture content do not present a problem; it is only those that are wet at one time and dry at another that will cause a rise and fall of the ground surface. Soil moisture content is affected by climate and weather conditions, vegetation, and the effects of civilization.

The magnitude of the rise and fall of the ground due to swelling and shrinking can be quite significant. Where buildings have been constructed over a boundary between expansive and nonexpansive soils, substantial structural damage has occurred. Also, measurements taken by the U.S. Geological Survey in Houston have indicated a rise of over 1 centimeter after an 8-hour period of rain following a dry spell. Bench marks set for our purposes should not be subject to such movements.

Consolidation

Consolidation of fill material is another type of near-surface ground movement. Fill is usually deposited loosely and will compact under its own weight over a period of time. Examples of fill areas include landscape improvements, levees, and disposal sites for trash, overburden, or dredge deposits. A bench mark supported by loosely deposited fill will settle as the fill consolidates.

Erosion

Sometimes bench marks are set in places where they are disturbed because of erosion. This is especially true of tidal bench marks, since they are set near bodies of water and rivers. River banks are gradually eaten away, and coastal sand dunes are built up, shifted, and torn down. Not only can a bench mark drop in elevation or get washed out because the soil supporting it is eroded, but it can also become lost by being buried.

Slope Movement

The final near-surface movement of concern is slope movement. Gravity tends to make soil and rocks slide down an incline. Types of slides vary from devastating rock and mud slides to creep. Soil type and moisture content determine what type of slide will occur and the rate of movement. Utility poles leaning downhill usually indicate that the soil is gradually sliding. They lean because the soil slides faster near the surface than at the depth of the bottom of the poles. A bench mark set on a creeping slope will imperceivably slide downhill, too.

PROBLEMS INHERENT TO MONUMENTS

Settlement

The makeup of the monument itself can have detrimental effects on its stability. For one thing, a monument can be too heavy for the soil beneath it to support it without consolidating or spreading. For example, a concrete post set in a swamp will settle. Though the post is relatively light, the bearing capacity of the soil is extremely low. Buildings do the same thing if the bearing capacity of the soil beneath them is not quite high. In fact, many buildings are designed to settle during construction and for some years after.

Corrosion

The problem of corrosion in bench marks was brought to light just a few years ago when a mark setter pulled up the top 8-foot section of a copper clad rod which was set to about 100 feet. The bench mark had been in the ground for only 10 years before it corroded so severely at the first joint that the top section pulled out of the coupling.

The principle behind the corrosion of a copper clad rod is the same as the principle behind attaching zinc anodes to the hull of a steel vessel. Zinc has a higher electrical potential than steel. It gives up electrons more freely than steel, tending to spare the steel from giving up its electrons. The zinc actually corrodes faster and the steel slower than either of them would standing alone. In the case of the copper clad rods, the iron core of the rod has a higher electrical potential than the copper coating and thus is sacrificed to protect the copper.

Galvanic series charts list metals and alloys in the relative order of their electrical potential. The charts usually list the more active metals above the less active ones. The exact order will vary, depending upon the environment in which the electrical potential is measured. Most often it is measured in salt water. The more two metals are separated in the chart, the greater the difference in electrical potential, and therefore the more galvanic corrosion which will occur if they are coupled. Metals close to one another will show less galvanic action regardless of whether both metals are high or low in the chart. Isolated metals (i.e., those not coupled with

others) are generally more corrosion resistant if they lie toward the bottom of the chart. Some of the more common metals and alloys, listed from highest to lowest potential, are zinc, aluminum, plain carbon steel, brass, copper, nickel, stainless steel, and titanium.

Environment plays a big part in the process of corrosion. Coupled metals that exhibit galvanic corrosion in one environment may be quite compatible in another. Similarly, an isolated metal may corrode quickly in one environment and slowly in another, while another metal may have the opposite performance. In general, highly acidic, basic, or saline environments are most destructive to metals.

Damage Inflicted by People

Though it is often much more obvious when a monument is disturbed by a person than by natural causes, the ramifications may be less detrimental. At least the condition of the monument will indicate what has happened. However, steps to avoid damage inflicted by people will be well worthwhile.

Damage due to vandalism is a concern about which little needs to be said. Damage caused unknowingly or without regard by construction workers and maintenance personnel can often be avoided with a little thought. The bulldozer is one of the biggest destroyers of bench marks. Buildings are erected, parking lots put in, highways widened and straightened, utilities run, and waterfront improvements made. Survey monuments in the area of construction are doomed to destruction. Similarly, the maintenance of existing facilities presents a hazard to survey monuments. Examples include the mowing of lawns and repair of underground utilities. These activities should be taken into account when setting a mark, or the monument may be short-lived.

TYPES OF RELIABLE BENCH MARKS

References

NOAA Manual NOS NGS 1, entitled "Geodetic Bench Marks," (Floyd 1978) details marks of a very reliable nature which should be set whenever possible. Due to limitations in equipment and the remoteness of many tide stations, these guidelines are not always possible to follow when setting tidal bench marks. Alternatively, the Users Guide for the Establishment of Tidal Bench Marks and Leveling Requirements for Tide Stations (Bodnar 1977) can be consulted. Additional marks of a satisfactory nature are described there.

Disk in Bedrock

A disk set in bedrock is by far the best type of bench mark. It is very stable--most bedrock is moved about only by deep sources of crustal movement. (Some types of bedrock are subject to shrinking and swelling, just as expansive clays are.) It is fairly safe from human disturbances--a properly set disk will even resist minor attempts of vandalism. It is inexpensive and

easy to install--material costs are about $5 and labor is about one-half hour.

One difficulty with this type of bench mark is in distinguishing bedrock from other rock. For mark setting purposes, any extensive rock formation is considered bedrock. Since only a portion is visible from the surface, though, it may be difficult to determine the extent of the formation. Use your judgment. Try not to set marks in outcrops of boulders or in a single, partially buried boulder. Use a pry bar to help make a decision. Boulders located in expansive soils are moved about as the soil mass swells and shrinks. Boulders are also heaved around by frost.

A few steps, sometimes neglected, are important to remember when setting a disk in bedrock.

(1) After drilling the hole for the shank, recess the rock around the top of the hole so the disk will set down into it. Make sure the bottom of the recess is level so the disk will not be tilted.

(2) Try not to set marks in concrete or mortar during freezing weather. If this cannot be avoided, use a special, cold-weather cement.

(3) Use clean, fresh water and make the mortar stiff. Stiff mortar is strong mortar.

(4) Fill the underside of the disk with mortar before placing it in the hole, so no air pocket is left underneath.

(5) Work the mortar up around the edge of the disk, even with its top surface. This will thwart attempts by vandals or souvenir hunters to dislodge it.

(6) To clean the top surface, sprinkle dry cement over it, and rub it with a rag using circular strokes.

(7) Cover the finished mark with a board, cardboard, or the like. This will keep it moist while it is curing, and also prevent rain from making it too wet.

Disk in Structure

When bedrock is not available, the next best type of bench mark to set is a disk in a massive structure. A "massive" structure is one that is both sizable and weighty. Buildings should be at least three-story concrete, steel or masonry structures. Never use curbs, bulkheads, slabs of concrete, pavement, or other small structures such as concrete posts. In addition to being massive, structures should be at least 5 years old to avoid settlement.

The foundations of structures used for bench marks should be at least as deep as the maximum frost penetration for the area, and a quarter as deep as the expected depth of swelling and shrinking of expansive soils. Frost penetration is given in figure 13 of the manual "Geodetic Bench Marks" (Floyd 1978) expected depth of activity in expansive soils can be determined using table 2

and figures 7-12 of the manual.

Although the disk will usually have to be set in a wall, with the shank horizontal and the face of the disk vertical, it is difficult to level to when oriented this way. If possible, set the disk in a horizontally oriented structural member. Make sure the spot chosen is an integral part of the main structure, or it will not have the stability offered by the structure.

Use the same careful measures for installing a disk in a structure as for setting a disk in bedrock. Take appropriate caution not to deface the structure. When drilling in brick use a star drill and hammer rather than a Cobra. One additional recommendation for vertically set disks is to work the shank down to the bottom edge of the hole so it does not settle askew before the mortar cures.

Rod Marks

Rod-type bench marks have been in use since the mid-1950's. Originally, they were lengths of copper clad steel rod joined with brass couplings. They were driven to "refusal" or some arbitrary cut-off point with a gasoline powered impact hammer. Changes have recently been made to the original design. The rods are now made of stainless steel, and refusal is no longer the principal criterion for determining depth.

Driving a rod into the ground to the point of refusal does not insure that the rod will maintain its elevation; it merely means that it will be fixed firmly in the soil. If the soil in which the rod is imbedded moves, so does the rod. A better procedure is to somehow anchor the rod below the level of active soil. This can be done by isolating the rod from the active zone of soil by enclosing the affected portion of the rod in a sleeve. The sleeved Class A rod mark does just that. However, it takes a drill rig to install this type of mark, so it will not be discussed further here.

Another way to anchor the rod below the level of active soil is to drive it more than twice as deep as the estimated depth of the active soil. Friction between the rod and the deep, stable soil should then be greater than friction between the rod and the active soil. Table 3 in the manual "Geodetic Bench Marks" (Floyd 1978) gives minimum rod depths based on this principle.

It is recognized that sometimes refusal will be met before this depth is reached. "Refusal" is a loose term. It depends on the driving energy of the particular impact hammer used, and the effort spent by the individual setting the mark. Every effort should be made to reach the depth specified in the manual. Remember that a rod firmly fixed in an active mass of soil will not be stable. On the other hand, when the minimum specified depth is reached, driving will sometimes still be quite effortless. In this case, continue driving until substantial resistance is met.

SUMMARY

It is important that bench marks set for our purposes are quite stable and long lasting. Nothing can be done about crustal motion, but bench marks can be protected from near-surface activity. The following reminders will help achieve this:

(1) Use foresight in selecting a site that will probably be safe from construction for a long time. Avoid the insides of highway curves.

(2) Set a disk in bedrock whenever possible. Try to differentiate bedrock from boulders.

(3) Select sites on high ground to avoid frost heave and slope movement.

(4) Use massive structures more than 5 years old and with historical significance if possible.

(5) Set a disk in an integral part of a structure, connected rigidly to the foundation.

(6) Select structures with foundations deep enough to counteract the effects of expansive soils and frost.

(7) Concrete posts are considered very small structures and should no longer be set.

(8) For rod marks or other specially constructed monuments use metals that are compatible with one another as indicated by a galvanic series chart.

(9) Avoid areas of fill, such as landscape improvements, landfill areas, and dredge deposits.

(10) Seek protection from maintenance equipment.

(11) Stay as far from salt water as practical and away from the surface of highways that are salted in winter.

(12) Avoid sand dunes and the outside banks of curves in rivers if possible.

One final remark: People sometimes give me details on bench marks they have set, or intend to set, then ask if the marks will move. The answer is "Yes, all marks move." But whether or not they will move significantly, I don't know. I cannot predict with great confidence the stability of individual marks. I can only say that if the guidelines in the bench mark manual are followed, the stability of bench marks in general will be much improved.

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DISCUSSION

Lt. Cdr. Bass: Did you say the concrete monument was no longer permitted?

Lt. Cdr. Floyd: It's no longer permitted to be set; that's correct. The problem with a concrete monument is, if it's located in an expansive soil, the effect of expansive soils usually goes down to quite some depth, so it's just riding in a soil that's moving up and down.

If all your marks in an area are set in the same soil, which is moving up and down, you won't notice any changes in elevation, because the difference in elevation between marks doesn't change. But if you've got one in bedrock someplace, and a rodmark, and a concrete post, you'll notice a change in elevation.

Any others? Thank you.

THEORETICAL OFFSHORE TIDE RANGE DERIVED FROM A SIMPLE DEFANT TIDAL MODEL COMPARED WITH OBSERVED OFFSHORE TIDES

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ABSTRACT. A simple Defant model, based on the M_2 constituent, is presently used by the National Ocean Survey to estimate the offshore range of the tide, with observations at coastal tide stations of the actual tide supplying the necessary boundary condition for the model. The calculated values provide preliminary tide correctors for soundings obtained in offshore hydrographic surveys. Using offshore tide data from Deep Sea Tide Gage (DSTG) deployments and Offshore Telemetering Tide System (OTTS) buoys, the quantitative effects of the continental slope and shelf on the incoming semi-diurnal tide are discussed, and anomalies in the predicted tide curve due to Hurricane Belle are shown. Comparison of the observed tide range with the theoretical tide range reveals the need to modify the initial Defant model, which is accomplished by decomposing the range into its major harmonic constituents, resulting in an improved calculated offshore range.

INTRODUCTION

The National Ocean Survey (NOS), NOAA, has recently collected offshore tide data in support of major hydrographic surveys in the New York Bight and in waters of the Mid-Atlantic States. The data obtained have proven valuable in the reduction of hydrographic soundings to chart datum and are used here to verify a simple model which provides preliminary tidal zoning for survey ships performing offshore hydrography (Martin and Earle 1976). In general, because hydrographic soundings are taken throughout the tidal cycle and not just when the tide is at a particular chart datum, corrections (called tide reducers) must be applied to the individual soundings for the height of tide at the time of the sounding. The soundings are corrected, or reduced, to chart datum (Mean Low Water on the U.S. east coast, Gulf Coast Low Water Datum on the Gulf of Mexico coast, and Mean Lower Low Water on the U.S. west coast). Tide reducers are usually one of the most significant corrections applied to hydrographic soundings; inaccurate reducers can lead to problems in junctioning separate hydrographic sheets and in resolving individual cross-line discrepancies within the sheets (Umbach 1976).

Soundings from inshore hydrographic surveys are usually reduced by applying tide data collected from a nearby station or by interpolating tide data obtained from two or three of the nearest stations that were in operation

during the survey. However, for offshore surveys it has been necessary to extrapolate tidal characteristics from an onshore station out onto the continental shelf. In many past instances, the range of the tide at a coastal tide station was simply assumed to be the same offshore, and the phase of the tide was estimated using shallow water wave theory as applied in the Manual of Tide Observations (USC&GS 1965).

General wave theory states that an incoming tide wave will have its basic sinusoidal form modified once it advances over a continental shelf. The wave increases in amplitude due to bathymetric effects. With this knowledge, NOS has adopted a simple Defant model (or method) to compute the range of the tide offshore (Defant 1929). The phase of the tide offshore is estimated by applying shallow water wave theory.

Given the range of tide at appropriate coastal stations and the bathymetry of the continental shelf along transects running from the stations out normal to the shelf, the Defant model provides the theoretical range of tide at any location along the transects. These theoretical ranges and phase of tide are then used to 'zone' the area of hydrography for a particular survey. The number of zones required depends on the rate of change in the area's tidal characteristics. Thus, a sounding taken in a specific area will have a specific time and range corrector applied to the predicted tide (preliminary zoning used during the survey) or observed tide (final zoning after the field work) at a coastal station.

The preliminary tide zoning for NOAA's MESA (Marine EcoSystems Analysis) and DELMARVANC (Delaware, Maryland, Virginia, North Carolina) projects are shown in figure 1. This zoning is based on transects run out from Sandy Hook, New Jersey, for MESA and out from Bethany Beach, Delaware, and Virginia Beach, Virginia, for DELMARVANC. Figure 2 shows the relative locations of the offshore tide gages from which data were collected during both surveys.

Deep sea tide data were collected for 6 months in the MESA Project (August 1975 to February 1976) and the DELMARVANC Project (June 1976 to November 1976) using gages deployed in deep water off the continental shelf and slope. Tide data from the shelf gages shown on the MESA transect (MESA 9, 10, 11, and 22) are presented in the MESA New York Bight Atlas Monograph 4 (Swanson 1976). The OTTS gages (OTTS 1 and 2) collected useful, continuous data for 15 days in August 1976.

The deep sea tide gage (Model B-DSTG, Gulf General Atomic) (fig. 3) is a self-contained pressure recorder capable of measuring small changes in hydrostatic pressure in depths of water up to 5,000 meters. The pressure transducer is a bourdon tube connected to a small tube that opens into an oil reservoir that is separated from the outside sea water by a membrane.

The changes in hydrostatic pressure brought about by variations in sea level cause the bourdon tube to rotate. The rotation of the bourdon tube is translated into an electrical signal by means of a stationary light source, a mirror mounted on the tube, and an array of photoelectric cells. This signal is then recorded as a function of time on a Rustrack recorder. The gage can record data up to half a year at a sampling rate of 30 minutes.

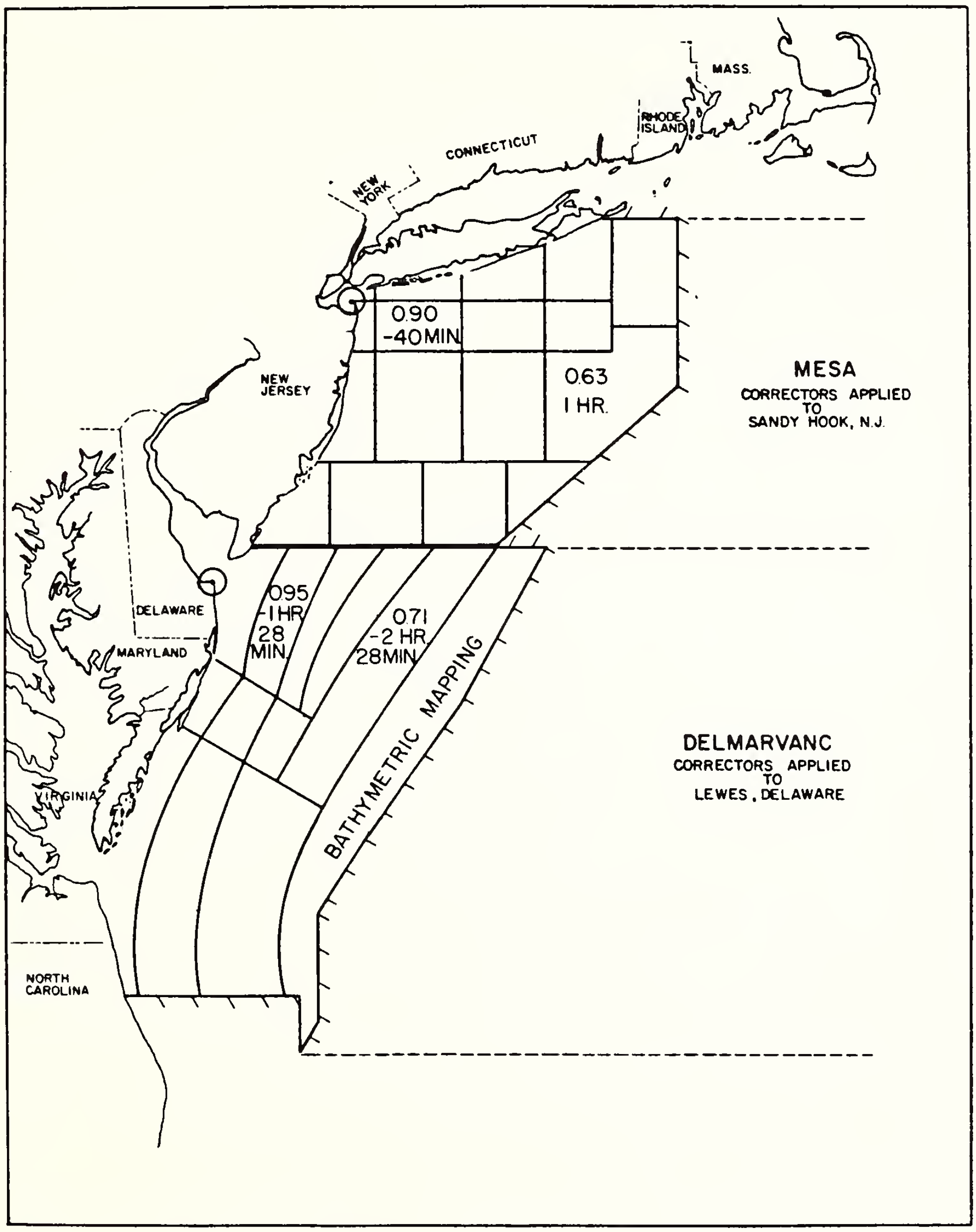

Figure 1.--Preliminary tidal zoning for the MESA and DELMARVANC projects. (The upper number in each box refers to the height ratio and the lower number refers to the time corrector to be applied to the predicted tide at the appropriate reference station.)

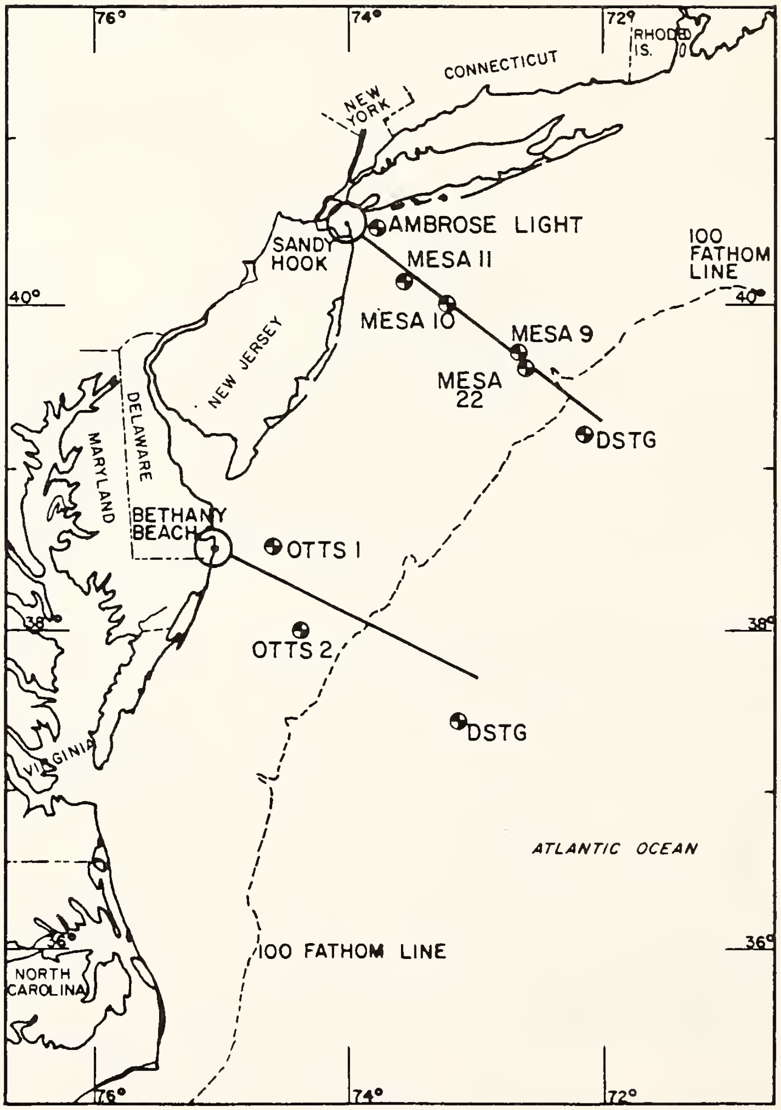

Figure 2.--Locations of the offshore tide gages and the transects utilized for computations in the Defant model.

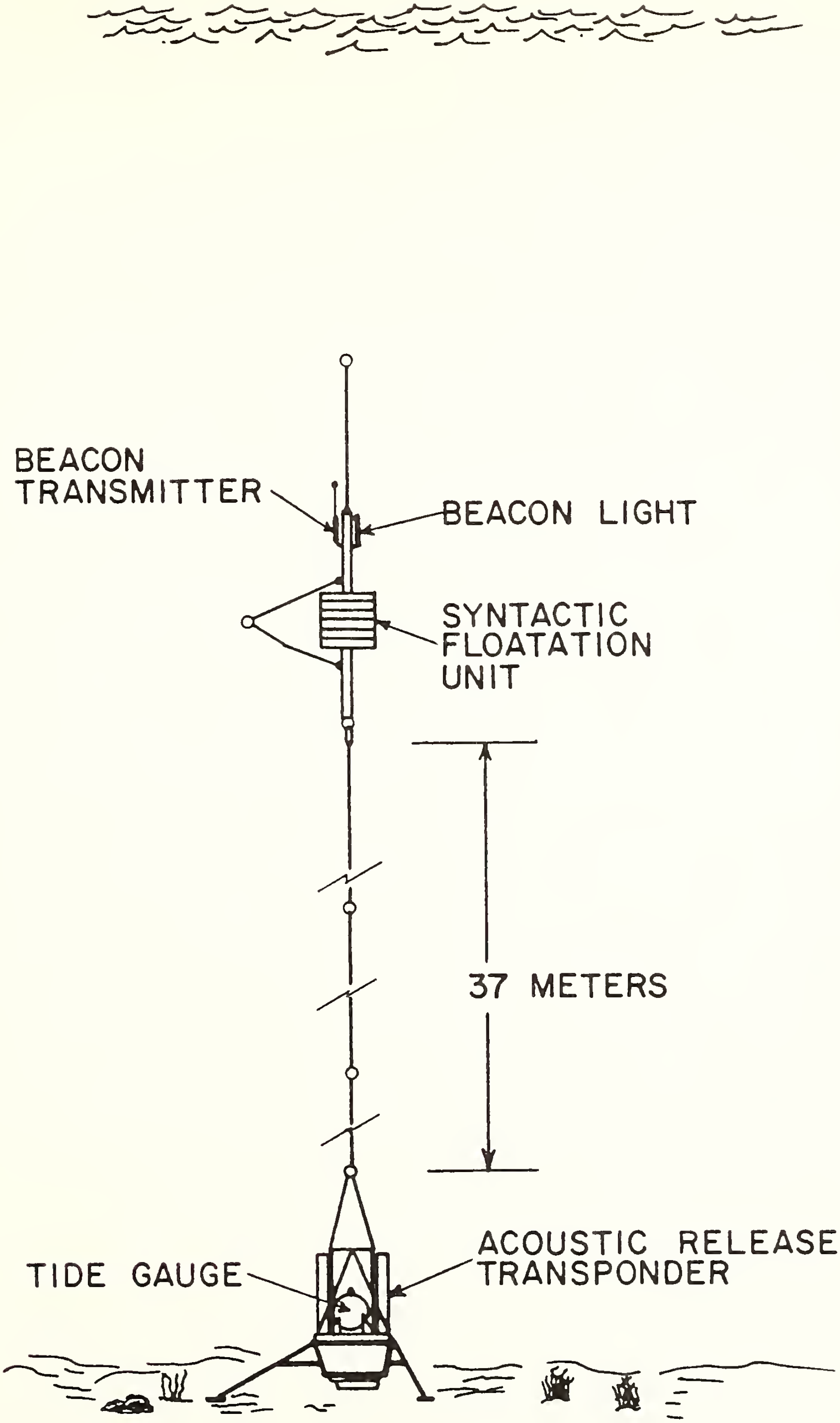

Figure 3.--Deep Sea Tide Gage (DSTG) mooring.

Data obtained from the MESA Deep Sea Tide Gage (DSTG) agree well with the data obtained from a Lamont-Doherty Geological Observatory gage located just northeast of the MESA DSTG. The amplitudes and phases of the M_2 constituent of tide from the MESA and Lamont gages are 40.5cm/191.2^o and 43.9cm/207.7^o, respectively (Martin and Earle 1976). All recent east coast DSTG deployments by NOS show a consistent range of tide of approximately 90 cm in a north-south band just off the continental shelf from the New York Bight south to the South Carolina-Georgia border (Martin and Earle 1976). The ranges and phases of tide found with these gages are also consistent with the estimates of Redfield (1958).

The differences between the theoretical (line labeled M_2) and observed range (circles) of tide along the transects shown in figure 2 can be seen in figures 4 and 5. These differences increase as the depth of water increases in each case, and the theoretical range of tide is consistently less than the observed range. Analysis of the DSTG and OTTS data has led to significant changes in the preliminary zoning originally provided to the hydrographic surveys as shown in figure 1. Although the theoretical and observed range differences at the locations of the DSTG's are on the order of 10 cm and 20 cm, progress has been made in refining the model. Figures 4 and 5 clearly show the effect of the continental shelf on the theoretical and observed tide. Figures 6 and 7 show the difference in the theoretical and observed wave travel times for each transect. The time differences are just under 1 hour for DELMARVANC and just over 1 hour for MESA at the locations of the DSGT's. The phase diagram for the MESA data (fig.6) exhibits standing wave characteristics, while the corresponding diagram for the DELMARVANC data (fig. 7) exhibits progressive wave properties.

An unexpected situation observed during the DELMARVANC project was the collection of simultaneous tide data across the continental shelf during the passage of Hurricane Belle in August 1976. The approximate path of the hurricane in relation to the tide gage locations is shown in figure 8. Approximate hourly positions are indicated by the dots superimposed on the path. Figures 9 and 10 are the plots of the height of the tide versus time for a 2-day period around the passage of the hurricane for the OTTS 1 and DSTG, respectively. The predicted hourly height curves reflecting the preliminary zoning are also plotted for each location. The predicted curves for the offshore locations were formulated by applying the appropriate tide correctors shown in figure 1 to be predicted tide at Lewes, Delaware. Wind speed and direction at 3-hour intervals at Atlantic City, New Jersey, are shown below each plot.

The effects of Hurricane Belle on the second high tide of August 9 can be seen when the observed and predicted curves are compared. The piling-up effect due to the hurricane winds on the high tide appears to decrease as the depth of the water increases. The OTTS 1 data show a large deviation from the predicted heights during the hurricane, while the DSTG plot shows no perceptible deviation that could be attributed to the hurricane.

These hourly height plots bring out the importance of knowing the correct phase of tide offshore as well as the range of the tide when considering hydrographic applications. The Defant method seems to satisfy the accuracy

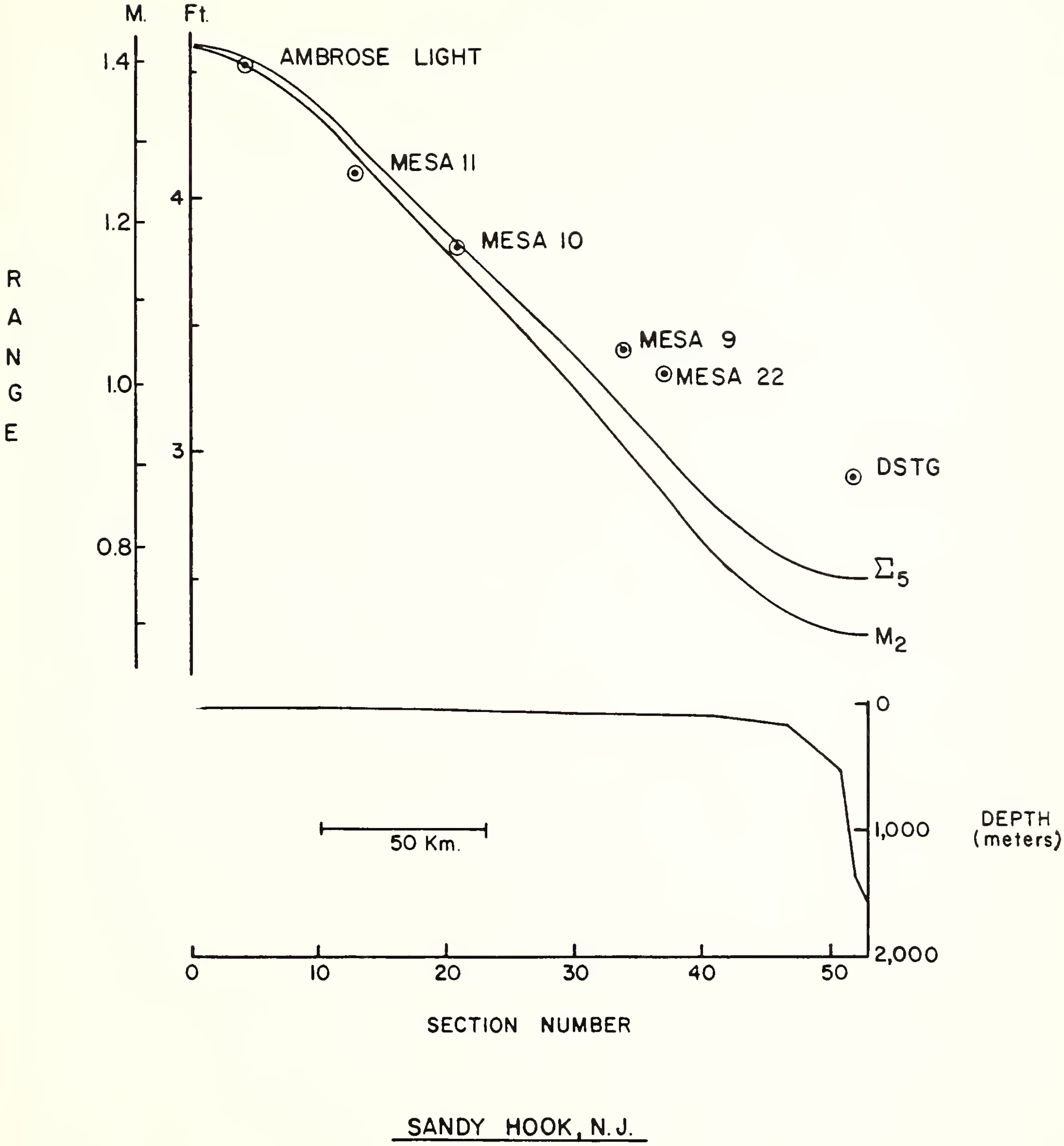

Figure 4.--Differences between observed (circles) and theoretical (M_2 and Σ_5) range of tide offshore for the MESA transect.

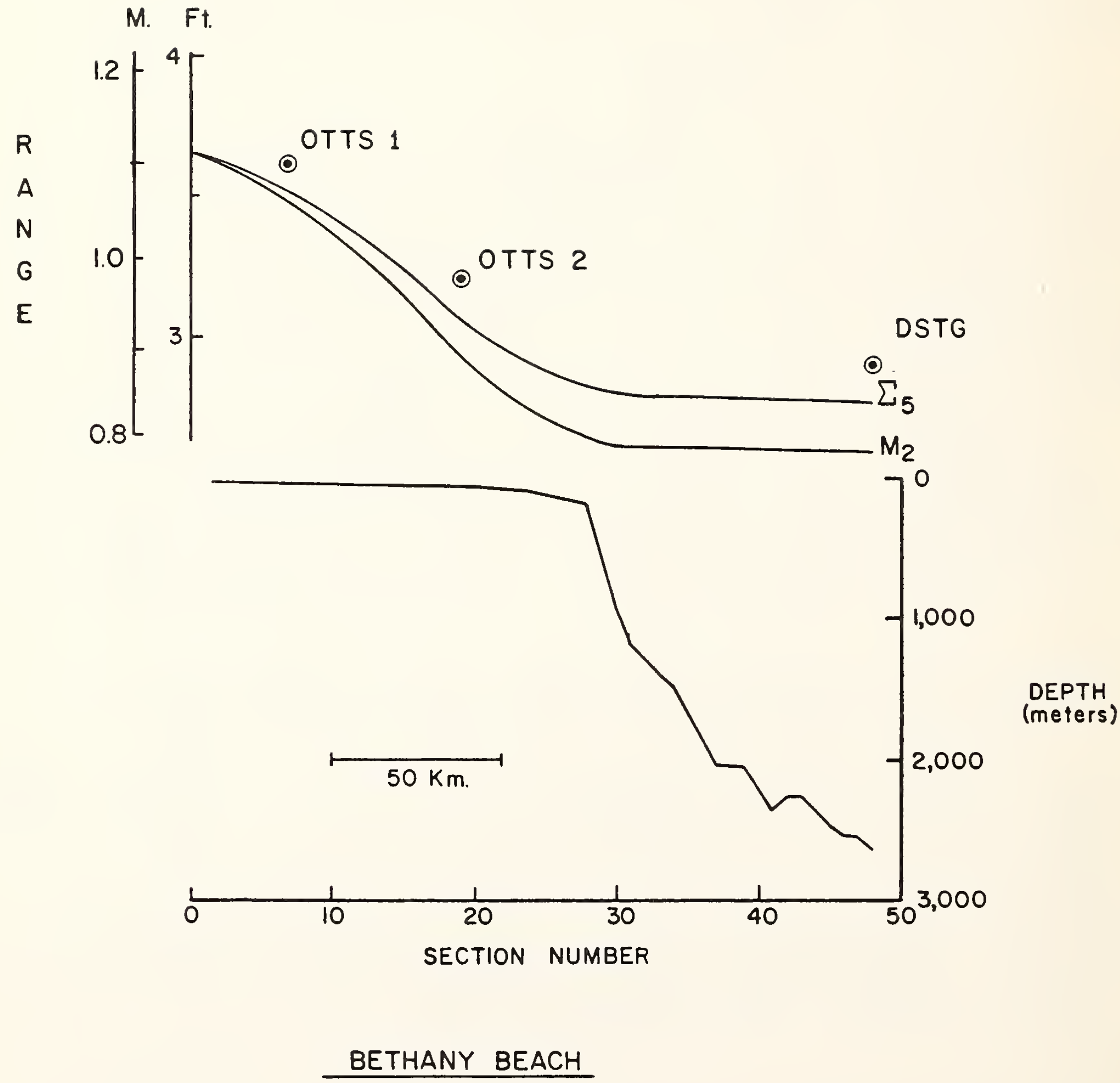

Figure 5.--Differences between observed (circles) and theoretical (M_2 and Σ_5) range of tide offshore for the DELMARVANC transect.

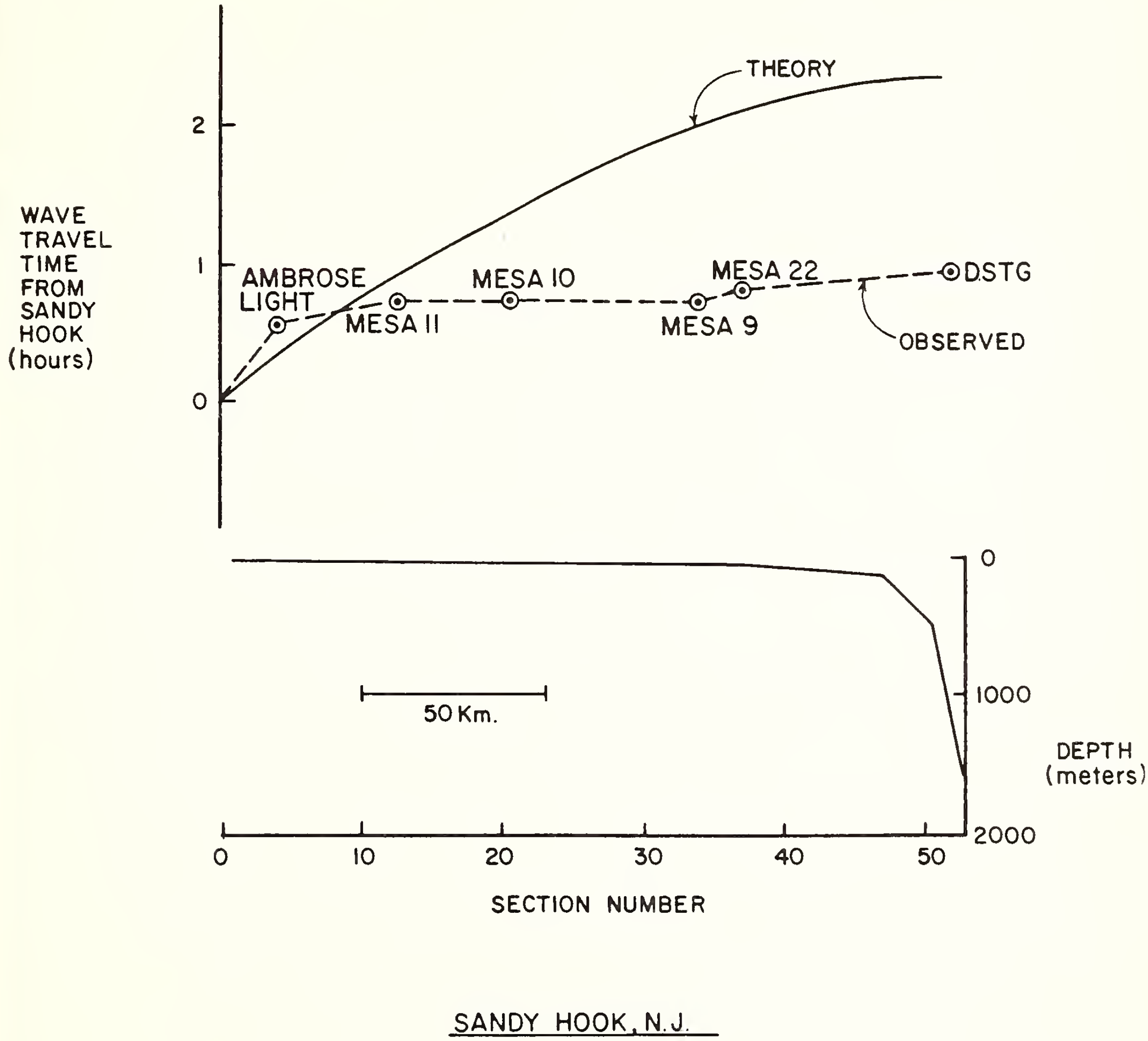

Figure 6.--Phase diagram showing differences between observed and theoretical (shallow water wave theory) wave travel times from Sandy Hook, N.J., for the MESA transect.

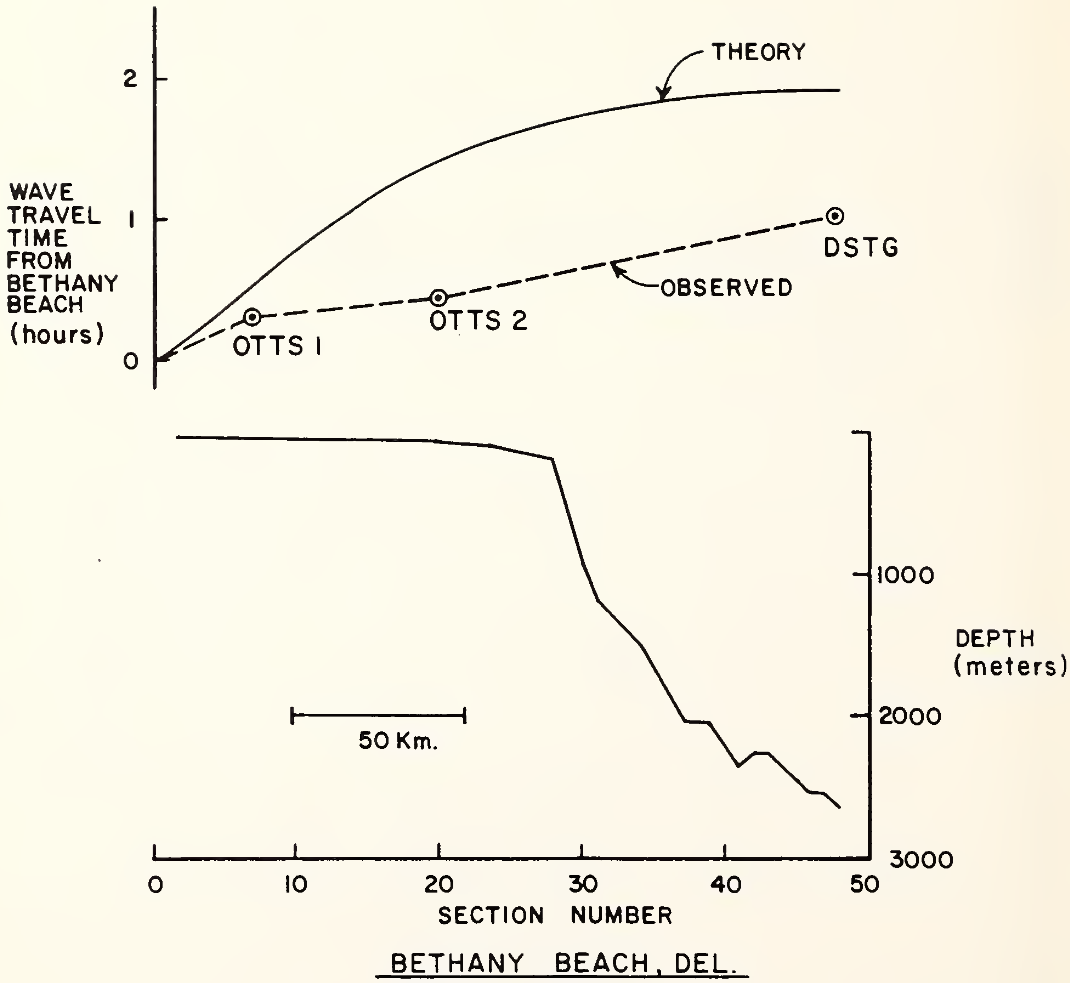

Figure 7.--Phase diagram showing differences between observed and theoretical (shallow water wave theory) wave travel times from Bethany Beach, Del., for the DELMARVANC transect.

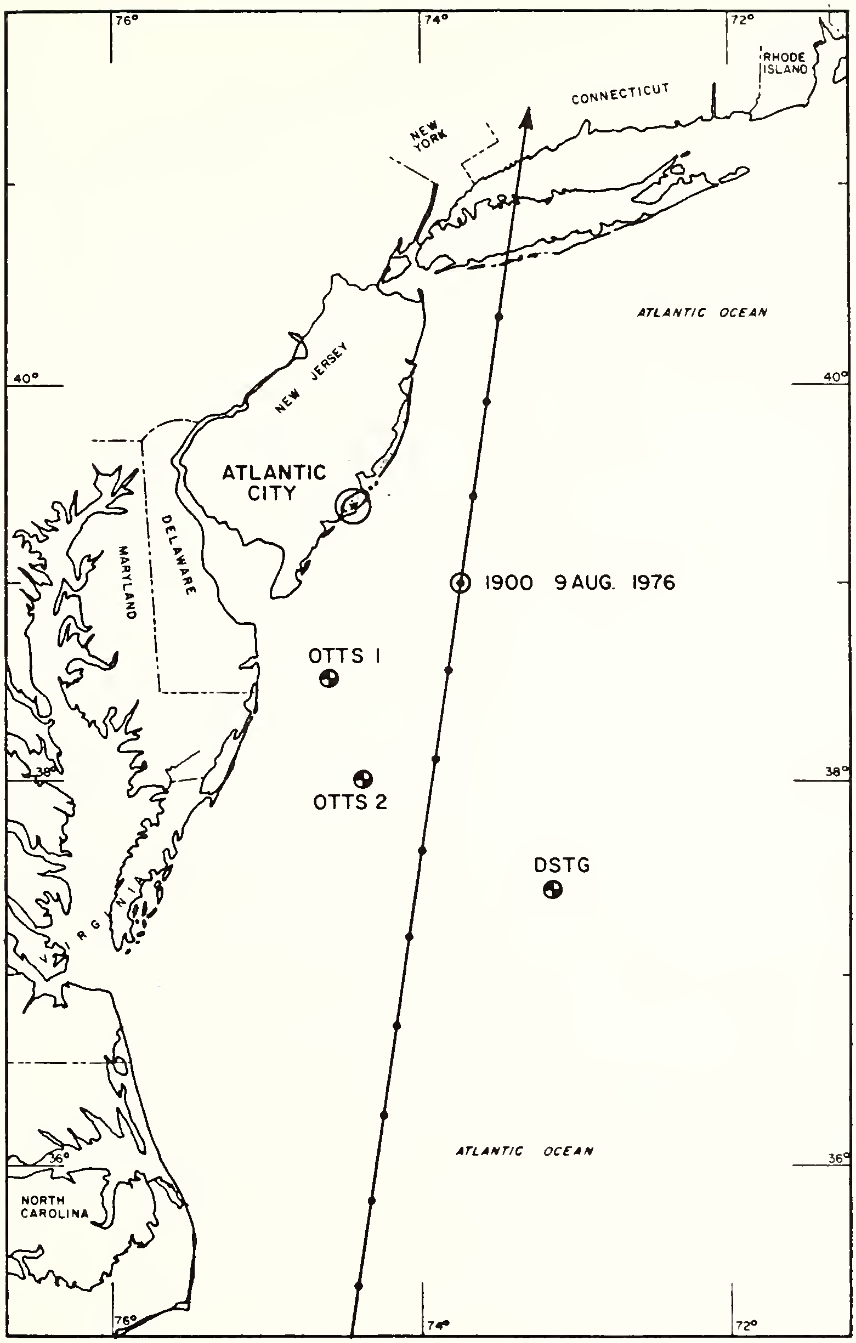

Figure 8.--Path of Hurricane Belle showing hourly positions.

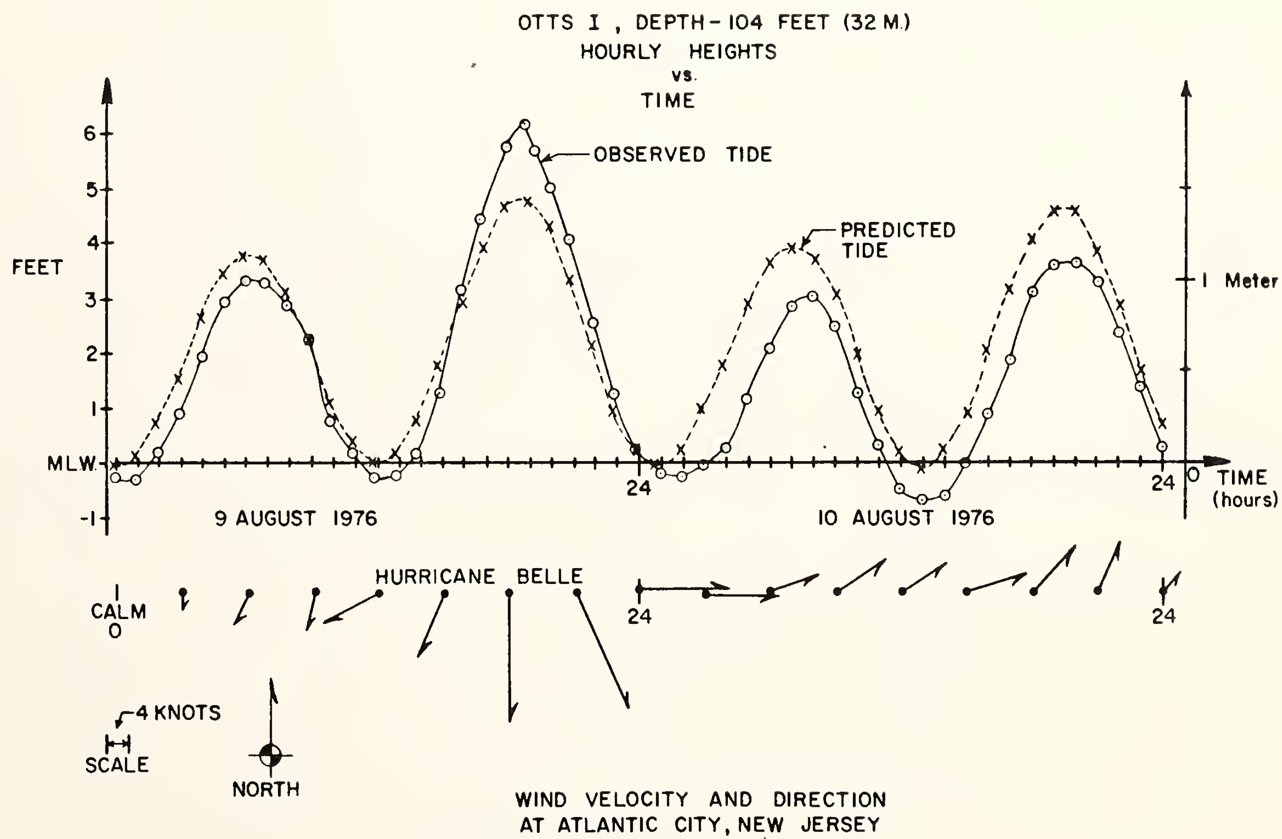

Figure 9.--Predicted and observed hourly heights for OTTS 1 during the passage of Hurricane Belle.

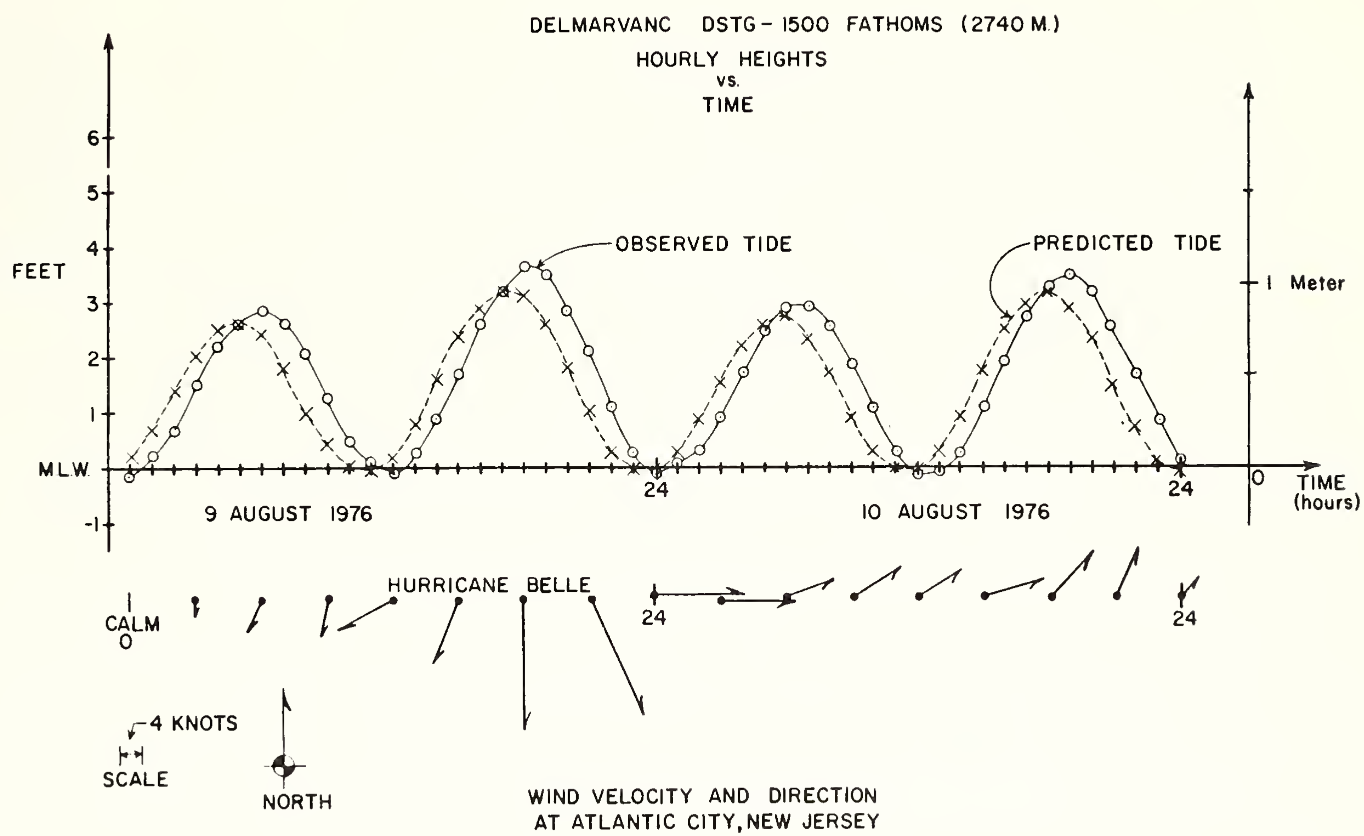

Figure 10.--Predicted and observed hourly heights for DSTG during the passage of Hurricane Belle.

requirements for range correctors, especially in deeper waters. However, use of the shallow water wave theory to estimate time correctors can introduce significant errors. The OTTS 1 and DSTG plots (figs. 9 and 10) show that the phase difference in the theoretical curve and observed curve at any particular time may lead to a height corrector which is as much as 1 foot in error.

DEFANT MODEL

The following is a brief description of the Defant model and of a modification that increases the accuracy of the range estimates offshore.

The coordinate system originates on the coast where the sea level intersects the shore (fig. 11). The gravity vector is in the negative y-direction, and the x-direction is orthogonal to the bottom contours. The controlling physics are continuity and a balance between the horizontal pressure gradients and the horizontal acceleration of the fluid. With the assumption of no advection, no rotation, and inviscidness, the controlling equations are:

1. The equation of motion:

$$\frac{\partial^2 \xi}{\partial t^2} = -g \frac{\partial \eta}{x} \qquad (1)$$

where g = gravity
x = distance from the origin
t = time
η = vertical displacement
ξ = horizontal displacement

2. The continuity equation:

$$\eta = \frac{1}{b(x)} \frac{\partial}{\partial x} (S(x)\xi) \qquad (2)$$

where S(x) = the cross sectional area of a plane perpendicular to the x-axis
b(x) = the width of plane measured perpendicular to the x-axis.

This set of equations can be solved by imposing a frequency of oscillation for the basin which is either some intrinsic frequency for a closed basin or some forcing frequency of an open basin. The boundary conditions are then enforced, and the set of equations are numerically piece-wise integrated. This approach is from Defant's method (1929) as shown by Sverdrup, Johnson, and Fleming (1942).

For the open coast, certain modifications must be made in the formulation of this problem. The assumptions are that the tide wave propagates inshore such that the wave crests are parallel to the shore and to the contours of equal depths. This model has been used by NOS in the past by assuming that the frequency of the wave corresponds to the M_2 constituent period, that the transect integrated over was orthogonal to the bottom contours, and that the point of origin is a coastal tide station. Examples of the transects for the MESA and DELMARVANC projects are shown in figure 2 where Sandy Hook,

DEFANT MODEL

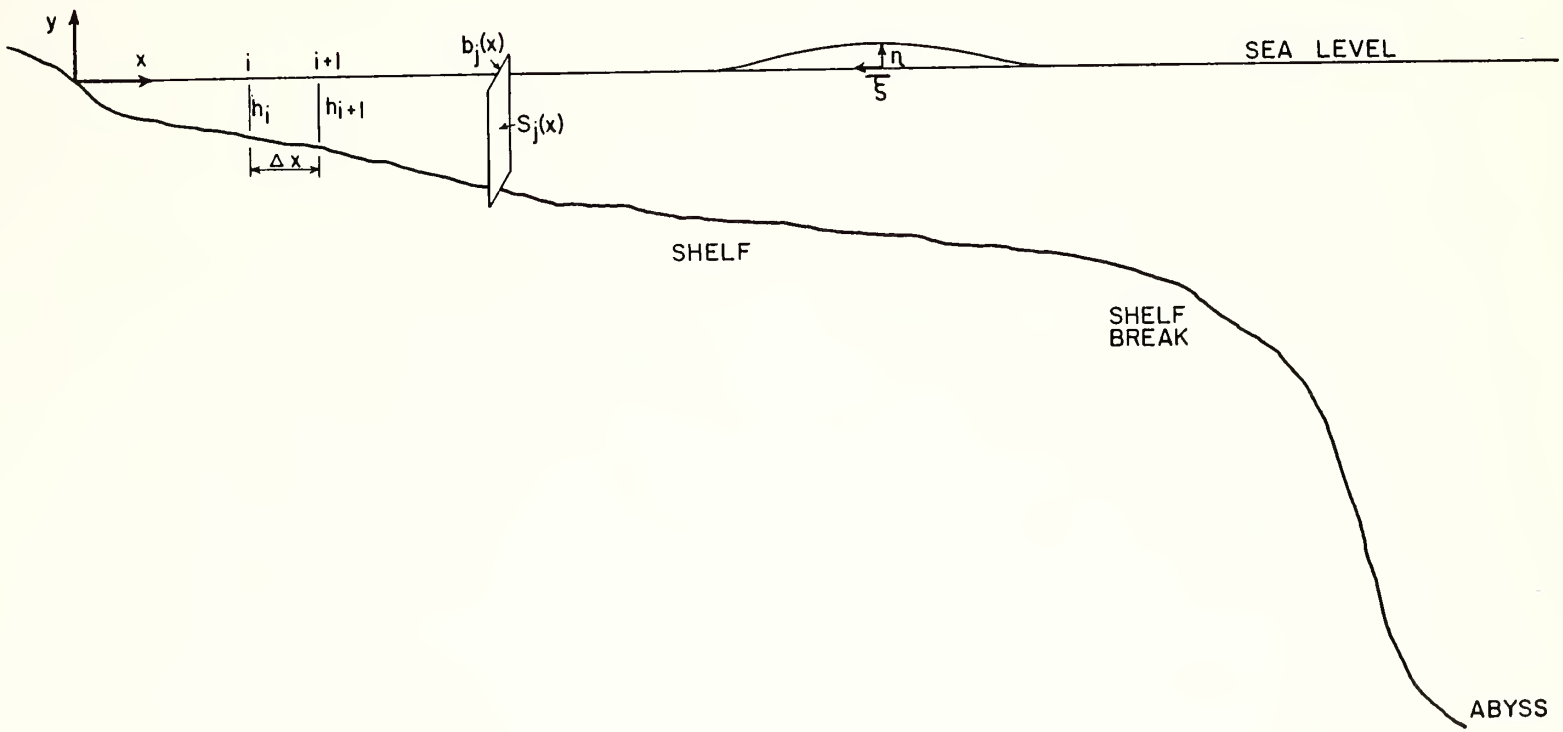

Figure 11.--Schematic for formulation of the Defant model.

N.J., and Bethany Beach, Del., were used as the points of origin. The integration steps applied were 4.00 km and 4.17 km, respectively.

The depths used for the integration were derived from NOS nautical charts, and the input frequency used was the M_2 frequency (or a period of 12.42 hours). The results are shown by the curve labeled M_2 in figures 4 and 5. The curves show a monotonically decreasing range of tide from the shoreline to the continental break. A constant range is present in the deep water off the Continental Shelf. This is indeed as it should be according to wave theory As the wave propagates into the shallower water, it increases in amplitude. It should be noted that the computed range falls below the observed range in each of the cases. This underestimation is due to the model constraints. An input parameter that has a large effect on the results of the model is that of the wave's period. The shorter the period, the faster the wave's range will decrease moving offshore. It was this fact that led to the modification of the basic method by considering each tidal constituent separately. This procedure involves using the harmonic constituents of the tidal data obtained at a controlling coastal tide station such as Sandy Hook or Bethany Beach. The five largest constituents are M_2, S_2, N_2, K_1, and O_1. It was assumed that all the significant tidal information was contained in these five components. Essentially the model is run five separate times and the results accumulated. The range of tide at the controlling station was multiplied by the amplitude of a particular constituent and then divided by the sum of the amplitudes of the five constituents. The frequency used corresponded to the amplitude of the specific tidal component. The final result is determined by adding the five separate partial ranges at each integration step. In this manner, the major forcing frequencies of the Moon and Sun are taken into account, not just the M_2 component as previously used. The result is that the range of tide does not attenuate as quickly offshore, because the other diurnal tidal constituents that are taken into account, specifically K_1 and O_1, have very large periods and decrease slowly offshore. The resulting estimates of the range offshore are therefore closer to the observed range. The estimated ranges labeled Σ_5 in figures 4 and 5 show an approximately 50 percent increase in accuracy.

The model is thus modified to give a more accurate result; however, the remaining discrepancies between theory and observation are noteworthy. These differences are due to the fact that in the model friction was ignored and the tide wave was assumed to propagate along the transect. The modifications show a better fit to the observed data at the Bethany Beach site than at Sandy Hook. The assumption that the wave travels along the transect is satisfied better at Bethany Beach than at Sandy Hook in the New York Bight. The New York Bight has a unique tidal response, in that the wave is affected by Long Island and is funneled into a 'corner' where the model assumptions are not satisfied.

Efforts to test the usefulness of the Defant model in areas other than the Atlantic coast are continuing in the Gulf of Mexico and on the U.S. west coast. The Gulf is a complicated area because of the dominance of the diurnal tide, with some areas switching from diurnal to mixed tidal characteristics within a month. The cophase lines for the major solar constituents in the Gulf are not parallel to the shoreline. Also, on the Pacific coast, the cotidal and corange lines are not consistently parallel to the

coast, thus violating the model constraints. The Atlantic seaboard appears to be one of the better suited sites for applications of the model presented in this paper, although further studies may make it more practical for these other areas as well.

CONCLUSION

The necessity to observe the actual tide during hydrographic surveys of an area is obvious; tide predictions are based on harmonic constituents which, in turn, are based on previous observations and do not take into account localized meteorological effects. The argument for the real-time observation of tides in offshore areas can be further advanced after noting the difference in the effects that an offshore hurricane can have on inshore and offshore tides. Hydrography, of course, is not conducted during hurricanes, but a storm surge can affect water levels for periods longer than the localized residence time of a storm. This may lead to situations where tide correctors applied to an offshore station do not reflect true offshore conditions.

The cost benefits of offshore tide gage development and deployment must be weighed along with the accuracy of the data needed for an overall survey objective. If tide gages are not deployed, offshore surveys must rely on the accuracy of numerical and computer models to predict offshore conditions. This, in turn, would require improved models and, in this specific case, a better method of estimating the phase of the tide. In any event, future deployment of shelf gages and DSTG's will be required for the verification of shelf models and global tide models.

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TIDAL DATUM TRANSFER STUDY

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ABSTRACT. Data collection procedures and results of a study to review methods of transferring tidal datums from a location with known datums to a location with unknown datums are discussed.

INTRODUCTION

The National Ocean Survey (NOS), responsible for the collection, tabulation, computation, and analysis of tidal data along the coastal United States, historically has collected long-term data from tide stations in major harbors and bodies of water in support of its nautical charting activities. Short-term data have also been collected in the estuaries and upper reaches of water bodies for reference low water datums and high water line mapping.

As the Nation's wetlands and coastal properties become increasingly more valuable, NOS has expanded its activities to include the development of a data collection network and new techniques for analyzing and using the data. These tidal data are used by NOS and other Federal, State, and private groups in the development of tidal datums, marine boundaries, control for coastal mapping, tidal predictions, storm surge analysis, control for coastal aerial photography, and various hydrographic and oceanographic projects. NOS is legally responsible for the accuracy of the data and the products it develops.

EPA Study

In 1976 NOS entered into a mutual agreement with the Environmental Protection Agency (EPA) to assist in the study of the relationships of marsh vegetation and tidal datums. In order to complete its mission it was determined that NOS would have to review the methods available for establishing tidal datums at project sites where the full range of the tide was not available. These methods are based on a relatively short series of tidal data (1 to 4 days).

Marine Boundary Programs

Within the past 10 years NOS has entered into mutual agreements with five* coastal States for the establishment and/or improvement of local tidal datum networks for the mapping of marine boundaries (usually the mean high water line). The data collected in these programs will be used by NOS to develop local tidal datums which, in turn, will be used by Federal, State, and private surveyors to map the various marine boundaries.

The Problem

Since the beginning of the State Marine Boundary Programs there has been much discussion at the Federal, State, and private level on the "proper and best" method for the use of tidal datums in locating the boundary lines they help to describe. One of the problems that has arisen is the need for an acceptable and accurate method for establishing a datum based on a relatively short series of tidal data from a point where the datum is known to a point where a datum is needed but unknown. In the simplest case this problem is encountered whenever a datum is transferred from a tidal bench mark to a local point on the ground. In the other extreme, the problem is also faced when a datum is transferred from one part of a hydrographic system (bay, lagoon, river, stream, etc.) where the datum is known to a different system (i.e., transferring a datum from a deep water control station to an area near the upper limits of a marsh).

Agreement and Controversy

Previous studies have been conducted by NOS, the States of Florida and New Jersey, Princeton University, and several private individuals on various methods for establishing datums. Most parties seem to agree on these two points:

- All methods have accuracy limitations which depend on the geographic and hydrographic conditions of the area. These conditions, which can be reflected in the difference of the tidal range, phase, time intervals, and general shape of the tide curve between the control station and the subordinate station, are a function of (1) the distance (hydrographical) between the control and the subordinate stations and (2) the hydrographic features between the control and the subordinate stations and/or the difference in the type of hydrographic system of the control station and the subordinate station.

- All methods have accuracy limitations that are dependent on the different seasonal and meteorological conditions present between the control and subordinate stations when the data are collected. These limitations are a function of seasonal or temporary fresh water runoff, and wind direction and speed.

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*The data collection phase has been completed in the New Jersey and Florida Marine Boundary Programs. The program in California will be completed in 1980, South Carolina in 1982, and Mississippi in 1981. Discussions are underway for the start of the Louisiana program in 1980.

The following questions generate the most controversy with regard to the establishment of tidal datums:

What methods are available for establishing tidal datums based on a short series of tidal data?

What is the "best" method for establishing a tidal datum? "Best" being a favorable combination of accuracy, repeatability, and practicality (with respect to what a prudent surveyor would consider to be cost, time, and manpower effective).

How can the different methods be tested?

What kind of accuracy can be expected from the different methods?

Are any of the methods invalid for establishing tidal datums? And if so, under what conditions?

What is the most efficient and accurate data sampling rate for establishing tidal datums?

How does the number of tides affect the accuracy of a datum?

What is the most efficient and accurate equipment for collecting the tidal data for establishing tidal datums?

What are the limits of the geographic, hydrographic, meteorological, and seasonal factors that affect the accuracy of the methods?

What methods are accurate and efficient in establishing tidal datums at (1) areas with a full tidal range, but with a different range than the controlling tide station; and (2) areas where the full tidal range is not measurable because the water body is dry for a portion of the complete tidal cycle; or the lower portion of the tidal cycle is restricted due to obstructions in the natural flow of the water?

The results and conclusions of previous studies conducted to answer some of these questions were found to be deficient in the following respects:

The study areas were too limited or unique to allow the results to be applied elsewhere.

A comparison between all the different methods available was not made.

The data sampling rate was not rapid enough and/or the equipment was not sensitive or responsive enough to monitor the minute changes to water levels expected in the upper limits of a marsh.

The study areas did not reflect the true conditions of the upper limits of a marsh where most work for boundary determination would be done.

An insufficient amount of data was collected (i.e., the data did not produce a statistically significant population for analysis).

There was no acceptable control datum available for comparison to the results of the different methods.

As a result of the many unanswered questions and under the direction of the former Director of NOS, Rear Admiral Allen L. Powell, the Office of Oceanography entered into an agreement with Mr. Bernard Zetler of the Scripps Institution of Oceanography to act as a technical advisor, examine the different methods of transferring tidal datums, review the tidal data collected by NOS and others in studies conducted to answer some of the above points, and to make recommendations and suggestions on the validity of the different methods available.

This report describes the data collection, tabulation, and computation phases of the project and presents the methods by which the data were collected, what equipment was used, and how the data were tabulated and prepared for analysis. The report will not make any conclusions or recommendations at this time. It will be the responsibility of Bernard Zetler of the Scripps Institution of Oceanography to review and study the data. An NOS technical report will be issued when any conclusions or recommendations are made.

SCOPE OF WORK

It was determined in the project planning that an attempt would be made to collect information on the following points:

What kind of accuracy can be expected from the different methods?

Are any of the methods invalid for establishing datums?

What is the most efficient and accurate data sampling rate for establishing a tidal datum?

How does the number of tides observed affect the accuracy of a datum?

What methods are accurate and efficient in establishing tidal datums at (1) areas with a full tidal range, but with a different range than the controlling station; and (2) areas where the full tidal range can not be measured because the water body is dry for a portion of the complete tidal cycle, or the low waters are restricted due to obstruction in the natural flow of the water.

It was felt that the point of controversy concerning the geographic, hydrographic, meteorological, and seasonal effects on datum accuracy could not be treated in a limited study and, therefore, will not be covered in this report. NOS did not compare different types of water level measuring equipment at this time because of the many parameters that would have to be monitored for a valid test.

METHODS

Six methods for establishing a tidal datum have previously been described and will be reviewed briefly:

The range ratio method assumes that the full range of tide at a control station is directly proportional to the full range of tide at a subordinate station.

The height method assumes that the peak elevation of a tide recorded at a control station is the same elevation in reference to mean high water as the same tide peak at the subordinate station.

The time method assumes that for the same tide recorded at a control and subordinate station the following elapsed times are the same:

> The elapsed time between that time a rising tide is at the elevation of mean high water and time of peak tide.
>
> The elapsed time between the time of peak tide and time when a falling tide is at the elevation of mean high water.

The modified time method assumes that for the same tide recorded at a control and a subordinate station, the lapsed time between the time a rising tide is at the elevation of mean high water and the time the following falling tide is at the elevation of mean high water are the same.

The differential leveling method (terrestrial leveling) assumes that the elevation of a tidal datum will remain at a fixed elevation in reference to an equipotential surface for a reasonable distance.

The least square method is a modification of the range ratio and height method that does not require the full range of tide. It assumes that for the same high tide recorded at a control and subordinate station, the amplitude ratio from the least squares solution on the upper portions of the curves is the same ratio as if these were a measurable full tidal range at the subordinate station.

SITE SELECTION AND RECONNAISSANCE

Based on the available funding, equipment, and manpower the study was limited to three marsh sites that met the following requirements:

Because of the availability of a relatively large number of recently developed secondary control datums and the relative accessibility to NOS headquarters in Rockville, Md., all study sites would be located within the State of New Jersey.

All marsh sites would be in the vicinity of acceptable NOS secondary control station(s) with established datums. (See fig. 1.)

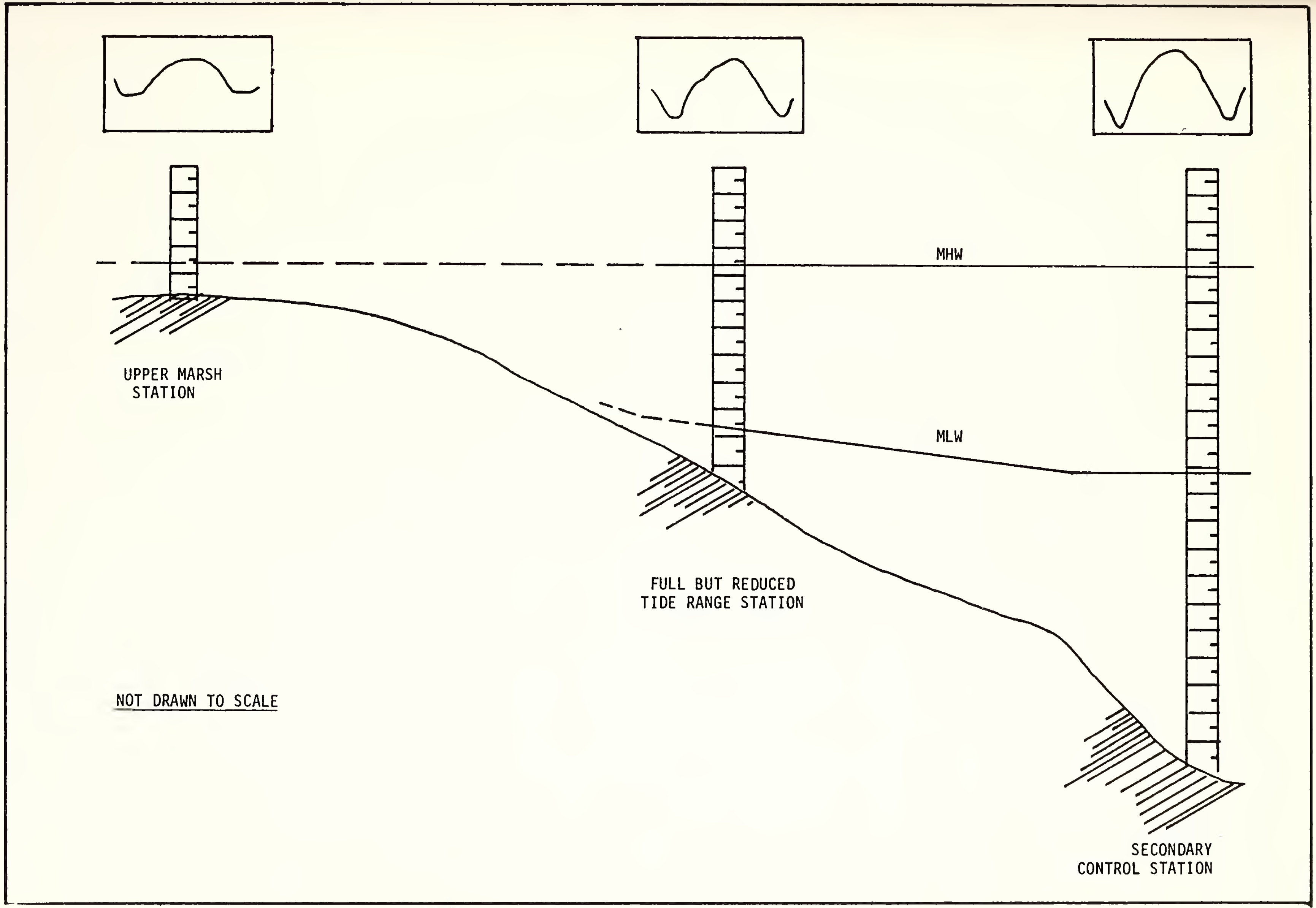

Figure 1.--Relative positions of tide stations.

Within all marsh sites there would be an individual tide gage site, preferably along the main thread of a tidal creek, that exhibits a reduced, but full, tidal range (approximately 50 percent of the controlling secondary station). (See fig. 1.)

Within all marsh sites there would be an individual tide gage site at or below the upper limits of the marsh where the full tidal range is not measurable because that area of the marsh is dry for a part of the tidal cycle, or the lower portion of the tidal cycle is restricted due to obstructions in the natural flow of the water. (See fig. 1.)

All individual tide gage staffs within the marsh sites would be situated to allow for reference to a common datum.

The NOS secondary control station at Steelmanville, N.J. (853-4778), and Tuckahoe, N.J. (853-1883), and the surrounding marshes were suggested as possible candidates for study. Upon investigation and a reconnaissance inspection in July, two marsh sites were chosen in the Steelmanville vicinity and one in Tuckahoe. (See fig. 2.)

The site selection included the study of aerial photographs, U.S. Geological Survey (USGS) 7.5-minutes series quad sheets, nautical charts, and historical tide data. Local trappers and fishermen were interviewed, and over 20 tidal creeks were inspected. The onsite inspections were conducted to ensure the characteristics of the test tidal creeks were as "natural and typical" as possible. The following characteristics were considered in the selection of the final test sites:

1. Creek profiles
2. Natural vegetation
3. Natural topography
4. Access for vertical control (leveling)
5. Tidal characteristics
6. Free flow of the tides

REFERENCE DATUMS

The following procedures were used to establish the "best accepted" reference datum at the study sites to which the results of the different methods for establishing datums would be compared.

Secondary Control Datums--Steelmanville 1 and Tuckahoe 1

The accepted values at the secondary control stations (fig. 3) had previously been established by the range ratio method during the New Jersey Marine Boundary Program (1976-78). The datums were referenced to the National Tidal Epoch (1941-59) through the local primary control tide station at Lewes, Del. The data collected at these sites during this study were used to

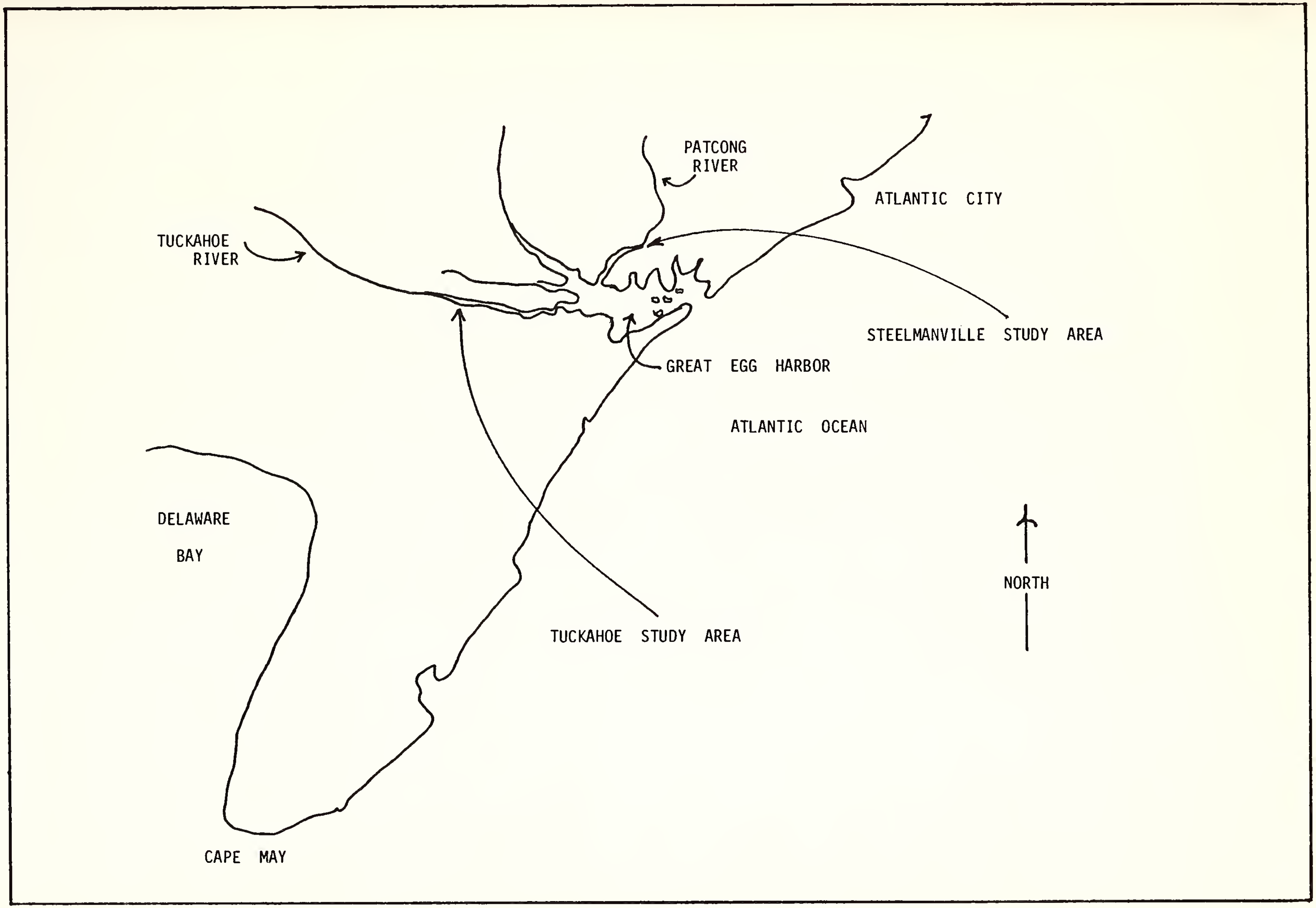

Figure 2.--Project area.

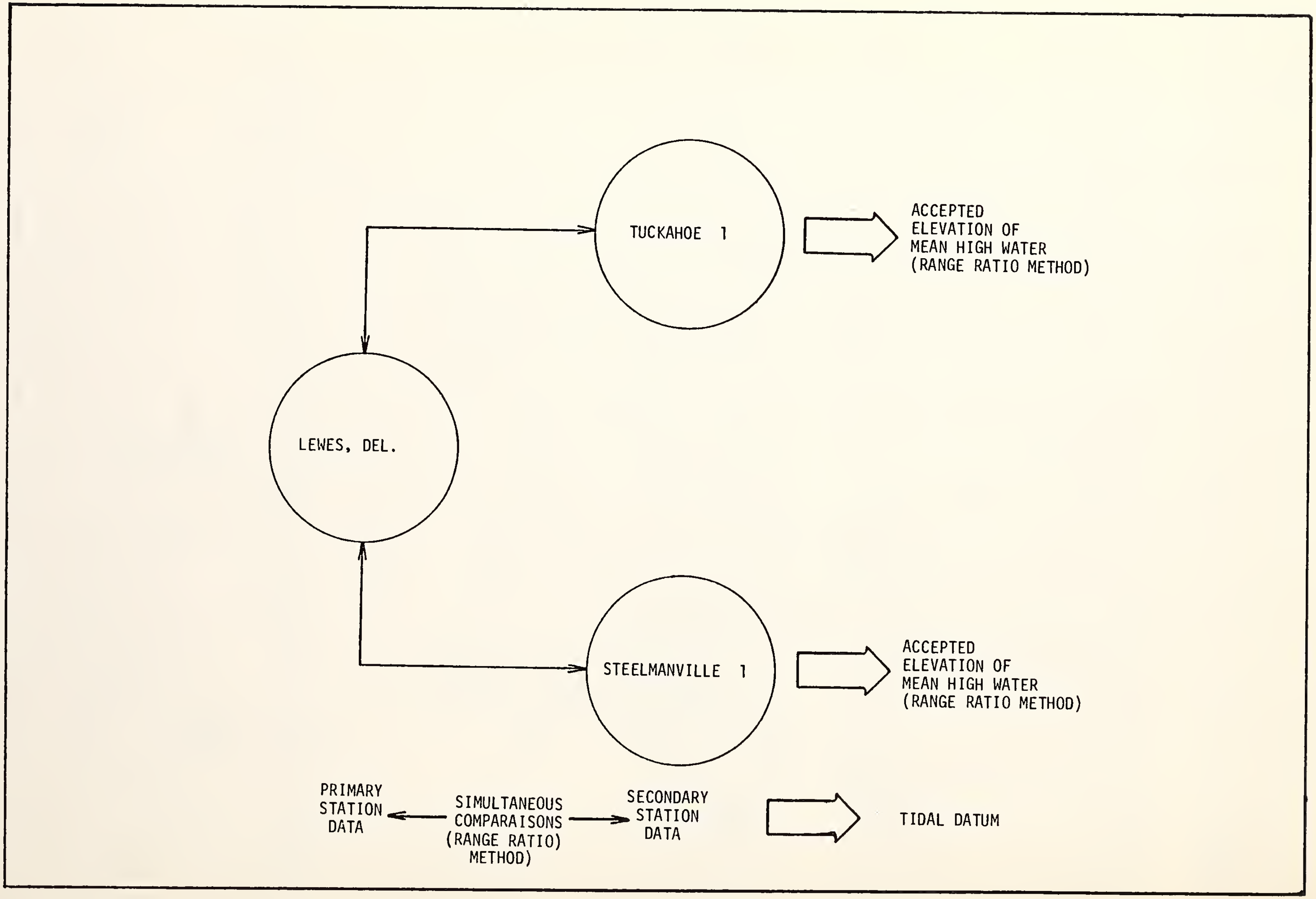

Figure 3.--Establishment of secondary station datums.

demonstrate the recoverability and verify the validity of the datums through the use of the range ratio method and the 3-month data series developed in the study.

Full, But Reduced, Range Stations--Steelmanville 2, Steelmanville 4, and Tuckahoe 2

The accepted values at the full, but reduced, range tertiary stations (fig. 4) were established by the range ration method during the study and referenced to the National Tidal Epoch (1941-59) through the local secondary station (Steelmanville 1 or Tuckahoe 1).

Upper Marsh Stations--Steelmanville 3, Steelmanville 5, Tuckahoe 3

Acceptable values of the mean high water (MHW) datum (range ratio method) could not be determined at the head of tide stations (fig. 5) due to the nature of the tidal curve; only the upper portion of the tidal cycle was measured. The local full, but reduced, range station datum was, in effect, transferred to the Upper Marsh station by differential levels and used as the "best approximate" reference value.

The individual (and group) values of the MHW datum that are determined in the comparison between the data collected at the full, but reduced, range stations (or the Upper Marsh stations) and the local secondary control stations by the short-term methods (height, time, modified time, and least squares) were computed and compared to the appropriate reference value. The comparison included the computation of the means and the standard deviation of the short-term method results and their relation to the reference values. (See fig. 6.)

GENERAL PROCEDURES FOR FIELD WORK

Tide Stations

Table 1 lists the station name, station number, installation date, removal date, length of data series collected, the sampling rate, and any major problems encountered at the stations operated in the study. (See figs. 7 and 8.)

Tide Gages and Sampling Rate

To meet high accuracy requirements for the tide gages and equipment, procedures from The Integrated Logistics Support Plan (National Ocean Survey 1980) were used. NOS collects digital tidal data with a sampling rate of 10 readings per hour, and has found this rate sufficient for establishment of tidal datums. Recently, questions have arisen concerning the need for a faster sampling rate to monitor the small water level changes of the upper reaches of tidal influence in estuaries. For this study, sampling of water levels will be at a rate of 60 readings per hour to test the need for an increased rate.

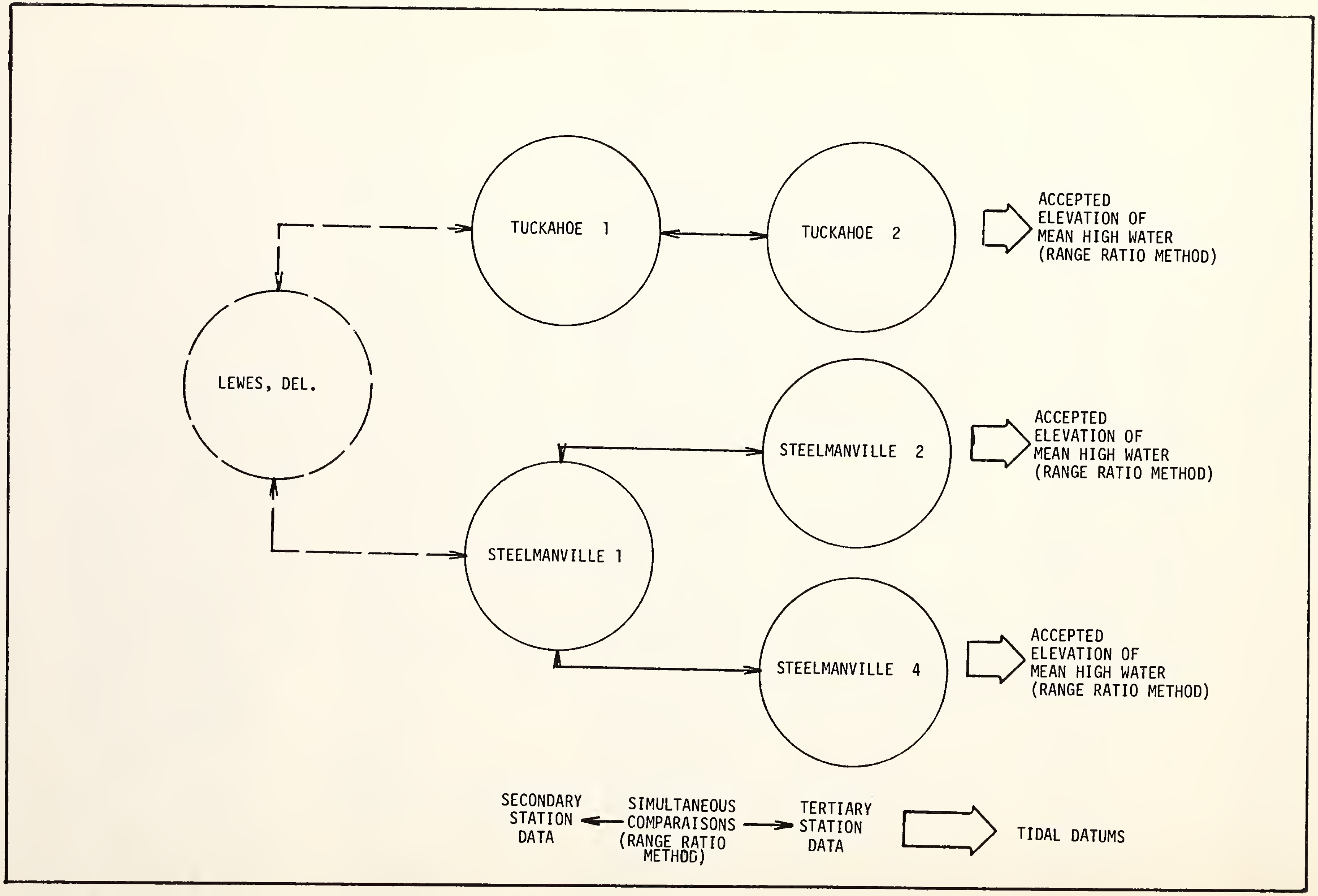

Figure 4.--Establishment of tertiary station datums.

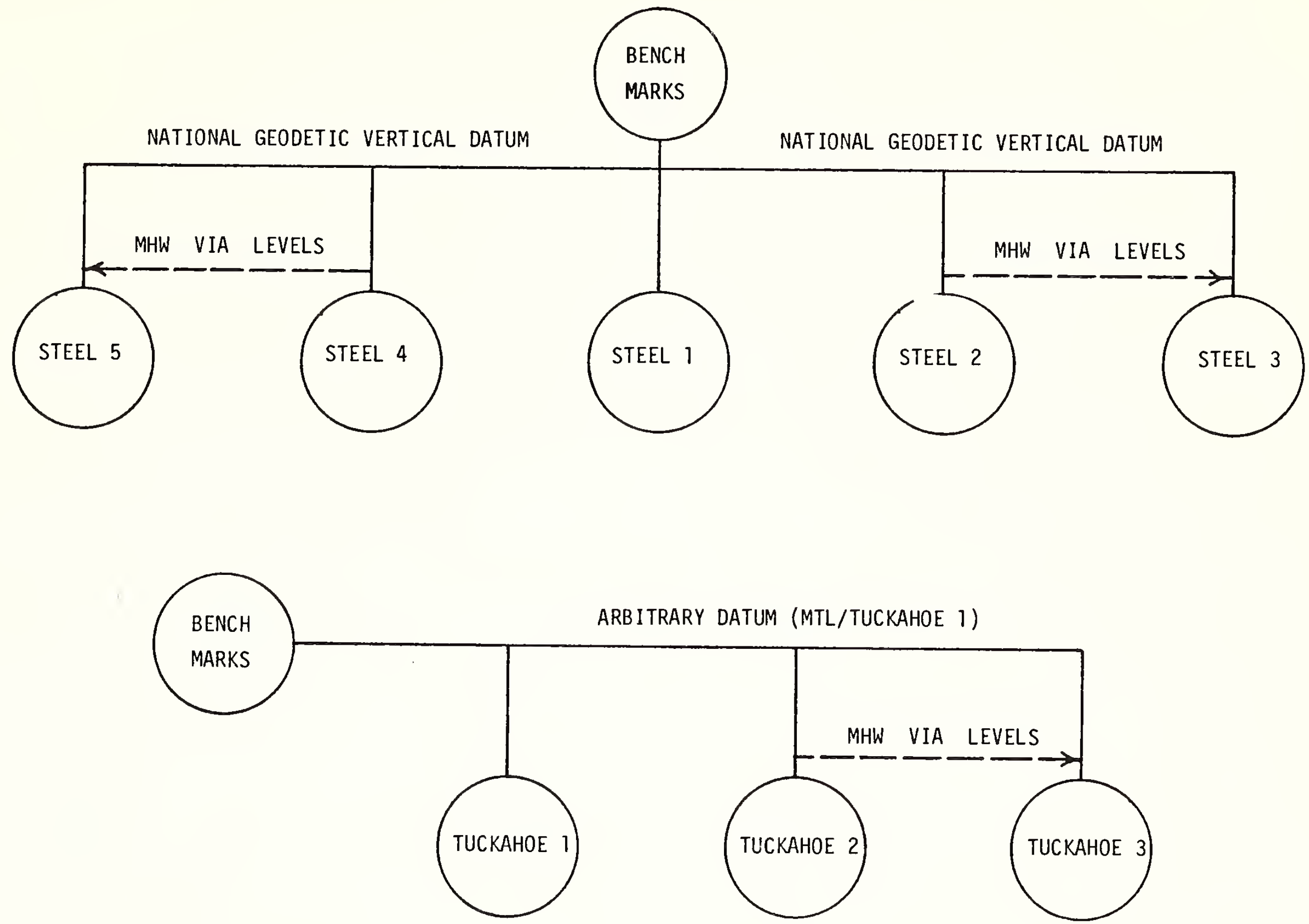

Figure 5.--Establishment of level network and reference datums (for upper marsh gages).

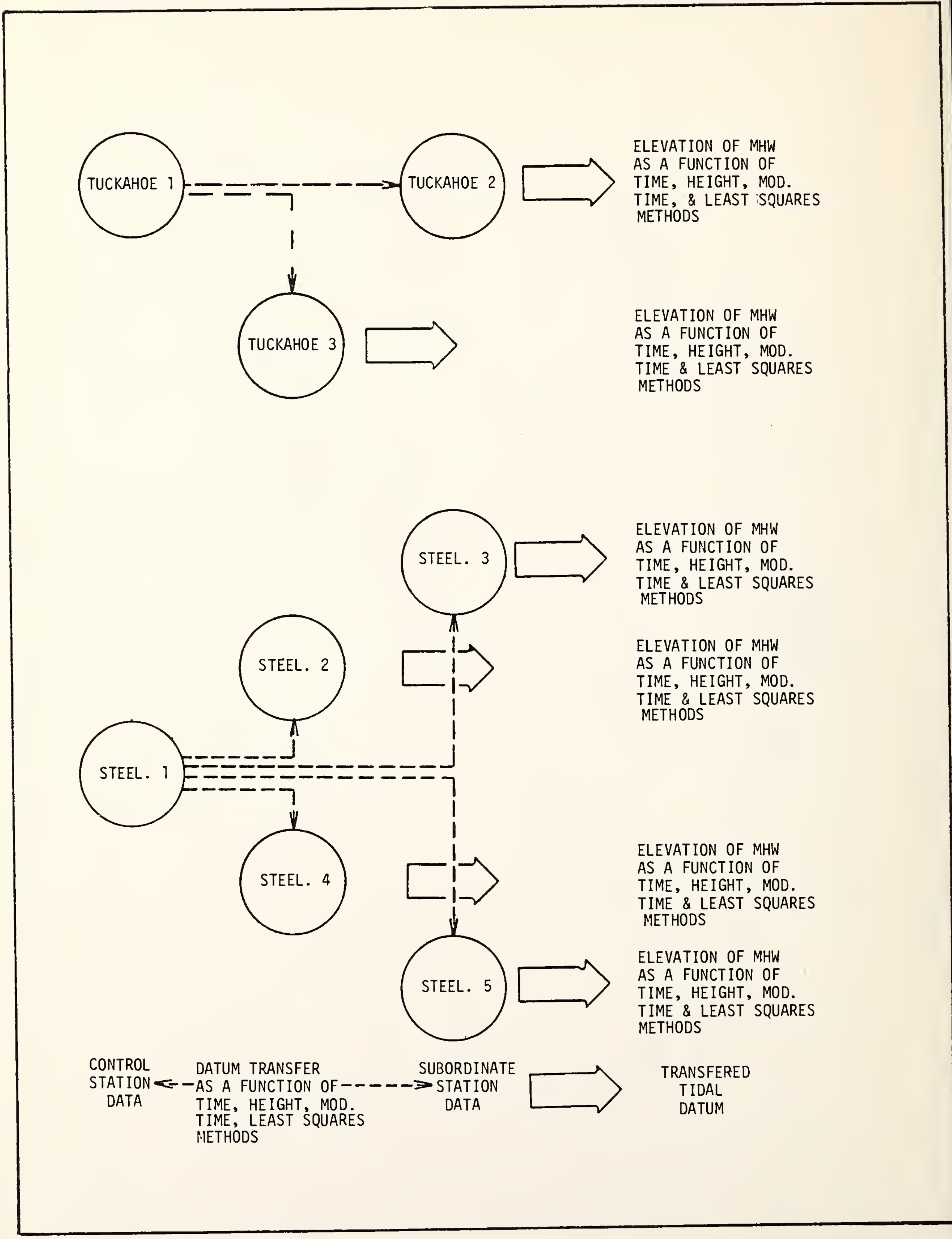

Figure 6.--Establishment of short-term datums.

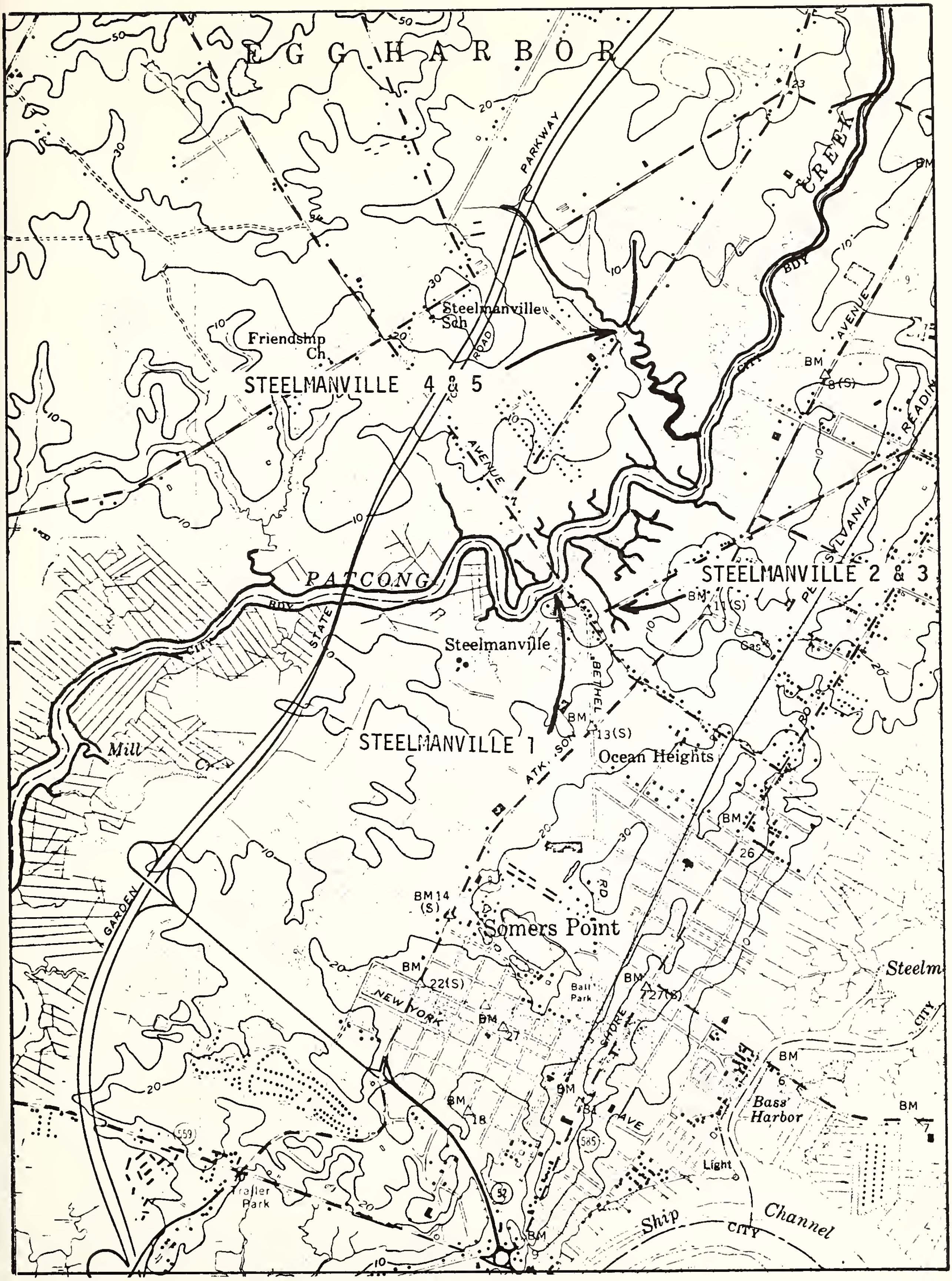

Figure 7.--Steelmanville study sites.

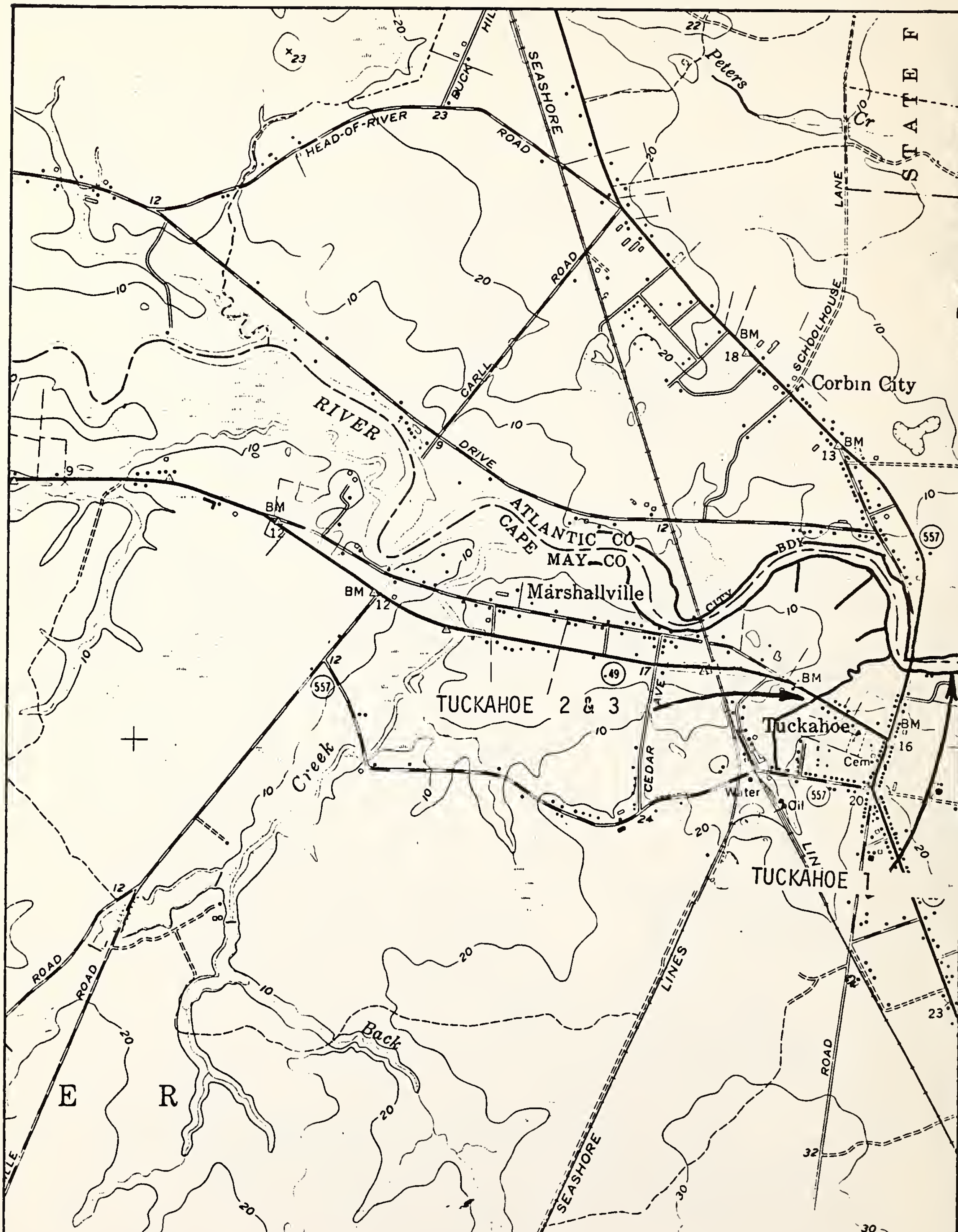

Figure 8.--Tuckahoe study sites.

Bench Mark/Leveling

All tide stations within the Steelmanville and Tuckahoe study areas were referenced by second order, Class 1 differential levels to a common datum for comparison within each area. The National Geodetic Vertical Datum Network (NGVD) is available near the Steelmanville study sites and was used as the reference datum for those stations. An arbitrary reference datum was used for those stations in the Tuckahoe study area.

Tide Observers

Local tide observers were hired and trained to monitor the operation of the tide gages, collect the tidal data, make staff gage observations, and report problems at the tide stations to NOS headquarters for action.

Creek Profile

To ensure the tidal flow was not restricted by natural or manmade obstructions and to better understand the tidal and fresh water influence of the study sites, profiles of the main thread of the tidal creek in the study sites were surveyed. For each tidal creek, the creek bed elevations were measured at regular intervals from the upper tide gage position, near the upper marsh gage sites, to the mouth of the creek.

Marsh Profiles

To better understand the relationship between the resultant elevations of mean high water determined from the methods reviewed in the project and their horizontal position in the marsh, a marsh transect in every study site was surveyed. Ground elevations were taken at regular intervals from the uplands to the tidal creek at the Steelmanville 3, Steelmanville 5, and Tuckahoe 3 study sites.

GENERAL PROCEDURES FOR DATA PROCESSING AND COMPUTATION

The following tabulations and computations were performed upon the tidal data collected at all study sites. (See fig. 9).

(1) Preliminary inspection and evaluation of data to ensure proper timing and gage operation.

(2) Review of the comparative readings of tide observations to determine staff/gage differences.

(3) Conversion of punched-paper-tape tide data to 7-track magnetic tape format.

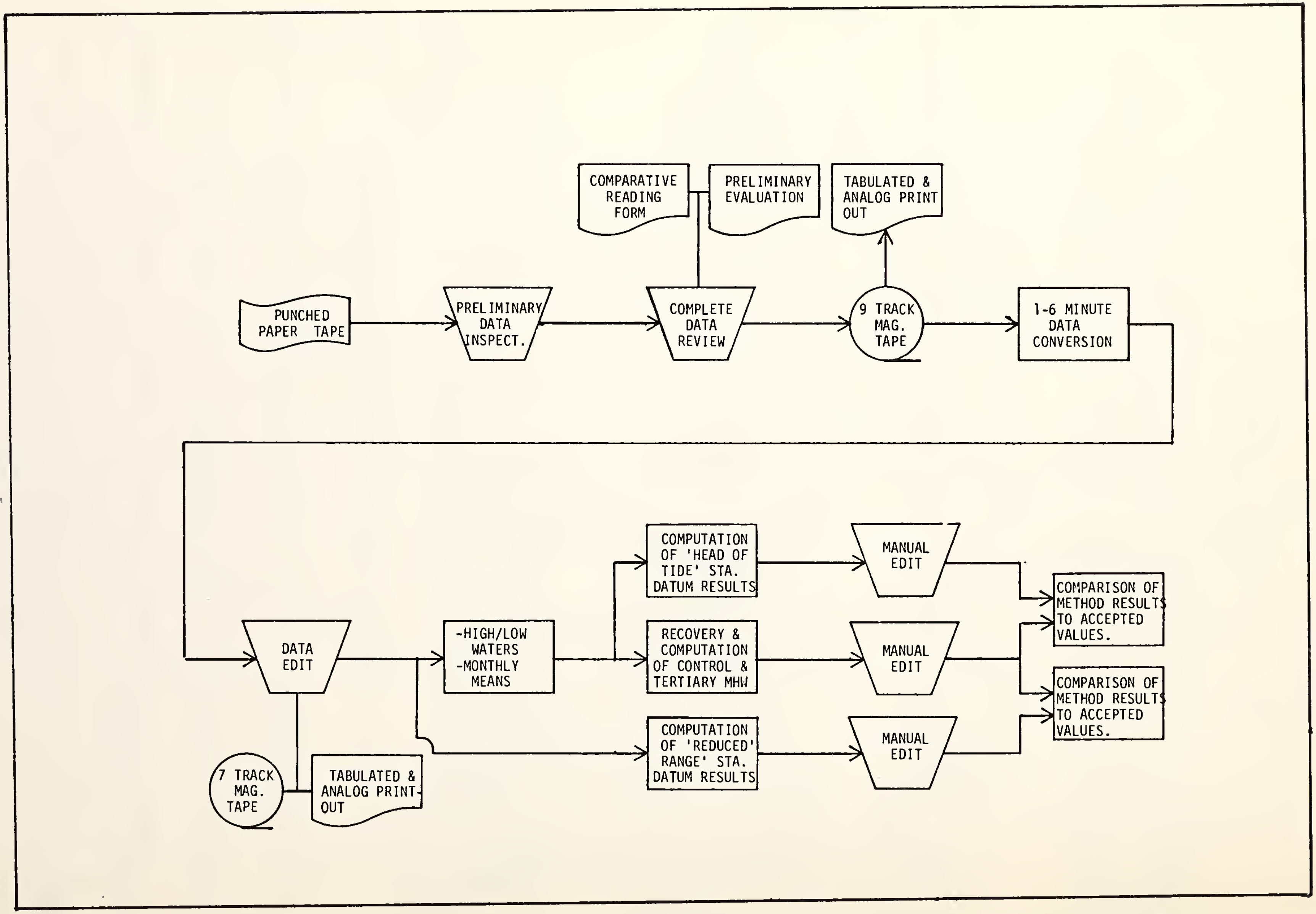

Figure 9.--Data processing and analysis.

Table 1.--Tide stations used to collect data

Station name and number	Installation date	Removal date	Length of data series (Days)	Sampling rate (Minutes)	Problem
Steelmanville 1 953-4778	7/26/79	11/8/79	95	1	Gage timer failure (10 days of data lost)
Steelmanville 2 953-4779	7/26/79	11/8/79	105	1	
Steelmanville 3 953-4780	7/27/79	11/8/79	99	1 and 6	Gage electrical failure (6 days of data lost)
Steelmanville 4 953-4781	7/31/79	11/8/79	90	6	Station vandalized (11 days of data lost)
Steelmanville 5 933-4782	9/27/79	11/8/79	16	1	Gage mechanical failure (26 days of data lost)
Tuckahoe 1 953-4773	7/26/79	11/7/79	104	1	
Tuckahoe 2 953-4884	7/25/79	11/8/79	106	1	Gage vandalized (8 days of data lost)
Tuckahoe 3 953-4885	7/25/79	9/26/79	63	1	Gage mechanical failure (7 days of data lost)

	Total Number	Percent
Station days of data possible	746	100
Station days of data collected	678	90
Station days of data lost	68	10

(4) Production of a tabulated printout and an analog printout of the 1- and 6-minute data.

(5) Conversion of the data that were collected at the 1-minute sampling rate to the NOS standard 6-minute format.

(6) Editing and correction of tide data due to mechanical deficiencies in gage operations and/or punched paper tape.

(7) Production of a tabulated printout and an analog printout of converted 6-minute data.

(8) Selection and printout of the daily elevations and times of high and low waters and monthly means.

(9) Recovery of tidal datums (range ratio method) at the secondary control stations, Steelmanville 1 and Tuckahoe 1, as compared to the simultaneous data collected at the primary control station at Lewes, Del.

(10) Computation of tidal datums (range ratio method) at the full, but reduced, range tertiary stations (Steelmanville 2, Steelmanville 4, and Tuckahoe 2) as compared to the simultaneous data collected at the secondary control stations (Steelmanville 1 and Tuckahoe 1).

(11) Computation (by the height, time, modified time, and least square methods) of the individual values of the mean high water datum for the following station pairs in table 2.

Table 2.--Station pairs

Station pairs	Control station	Subordinate station
01	Steelmanville 1	Steelmanville 2
02	Steelmanville 1	Steelmanville 3
03	Steelmanville 1	Steelmanville 4
04	Steelmanville 1	Steelmanville 5
05	Tuckahoe 1	Tuckahoe 2
06	Tuckahoe 1	Tuckahoe 3

(12) Computation and tabulation of the following statistical values determined from the above station pairs:

Individual values of the MHW datum based on 1, 3, 5, 7, 9, and 11 consecutive tides.

Mean values of the MHW datum based on 1, 3, 5, 7, 9, and 11 consecutive tides.

Standard deviations of the individual values of the MHW datum based on 1, 3, 5, 7, 9, and 11 consecutive tides.

(13) Computation and tabulation of a comparison of the individual and group values of the MHW datum as determined by the height, time, modified time, and least square methods, to the accepted value (subordinate station) of the MHW datum as determined by the range ratio method for station pairs 01, 03, and 05.

(14) Computation and tabulation of a comparison of the individual and group values of the MHW datum as determined by the height, time, modified time, and least square methods, to the value of the MHW datum as determined at the local full, but reduced, tide range station (range ratio datum transferred by differential level) for station pairs 02, 04, and 06.

(15) Computation and tabulation of the following statistical values determined from the individual and group values of the comparisons made in 13 and 14:

Individual values based on 1, 3, 5, 7, 9, and 11 consecutive tides.

Mean values based on 1, 3, 5, 7, 9, and 11 consecutive tides

Standard deviations of the individual values based on 1, 3, 5, 7, 9, and 11 consecutive tides.

ACCURACY STATEMENTS

Levels

All differential levels run between the bench marks and tide staffs were completed to second order, Class 1 standards. Based on the standard error allowed ($\pm$ 6 mm $(k)^{\frac{1}{2}}$), table 3 shows the maximum error allowed and observed for the differential levels between the established primary bench mark and the tide staffs used in the study.

Manual Tide Staff Observations

The tide staff and its relative elevation to the permanent bench marks is the primary reference for any series of tidal data. To reference the tide gage data to the bench marks, manual tide staff readings are compared to simultaneous tide gage recordings, and a constant is determined for the data series. Table 4 lists the number of the individual observations and the staff/gage constants used in the data analysis.

Table 3.--Maximum error between primary bench mark and tide staffs

From the primary bench mark to the tide staff	Distance from primary bench mark to tide staff (Miles)	Maximum allowable closure error (Feet)	Maximum observed closure error (Feet)
Steelmanville 1	0.04	0.005	0.001
Steelmanville 2	0.26	0.013	0.002
Steelmanville 3	0.26	0.013	0.002
Steelmanville 4	1.11	0.026	0.011
Steelmanville 5	1.11	0.026	0.008
Tuckahoe 1	0.10	0.008	0.002
Tuckahoe 2	0.60	0.019	0.006
Tuckahoe 3	0.78	0.002	0.005

Tide Gages--Water Levels

All tide gages were tested before and after the study for response and sensitivity to small water level changes as per the ILSP (National Ocean Survey 1980). The gage, stilling well, and float configuation were combined with the inspection and refurbishment effort to produce a maximum error of ± 0.01 feet for any individual raw data water level measurement.

Tide Gages--Timing

The tide gages operated at Steelmanville 1, Steelmanville 2, Steelmanville 5, Tuckahoe 1, Tuckahoe 2, and Tuckahoe 3 used the LED-Digital Timer from the Engineering Development Laboratory of the NOS Office of Marine Technology. This timer and the observation program set up to monitor the stations enabled these gages to collect data with a maximum timing error of ± 1 minute per week. The gages operated at Steelmanville 3 and Steelmanville 4 used a standard Leupold and Stevens crystal timer which, in this study, also collected data with a maximum timing error of ± 1 minute per week.

Tidal Datums

The accuracy of an established tidal datum is dependent on a number of factors which include:

The length of the data series at the project station for which the datum applies.

The use of a secondary and/or primary tide station for comparison with the project station.

The length of the data series (weight of the datum) at the controlling secondary station (if applicable).

Table 4.--Individual observations and staff/gage constants

Station	Length of series (Days)	Number of observations	Staff/Gage difference 1/ Mean (Feet)	S.D. (Feet)	Number of obser. used for analysis	Mean staff/gage used for analysis
Steelmanville 1	95	70	- 12.10	0.036	68	- 12.10
Steelmanville 2	105	58	- 10.02	0.040	54	- 10.01
Steelmanville 3	99	51	- 10.04	0.029	48	- 10.04
Steelmanville 4 2/	90	12	- 9.39	0.024	12	- 9.34
		6	- 10.00	0.023	6	- 10.00
		4	- 20.00	0.024	4	- 20.00
		21	- 43.33	0.029	20	- 43.33
Steelmanville 5 3/	16	5	- 39.31	0.010	5	- 39.31
		6	- 10.00	0.008	6	- 10.00
Tuckahoe 1	104	55	- 15.47	0.027	54	- 15.47
Tuckahoe 2 4/	106	23	- 10.01	0.023	22	- 10.01
		37	- 10.10	0.045	34	- 10.10
Tuckahoe 3 5/	63	10	- 9.99	0.010	10	- 9.99
		26	- 41.98	0.023	25	- 41.98

1/ Staff/gage differences not within two standard deviations of the mean were not used for the analysis.

2/ Steelmanville 4 tide gage was reset on 8/29, 9/12, and 9/24.

3/ Steelmanville 5 tide gage was on 10/29.

4/ Tuckahoe 2 tide gage was reset on 9/7.

5/ Tuckahoe 3 tide gage was reset on 8/15.

The similarity of the project station to the controlling secondary and/or primary tide station as it applies to:

The seasonal factors at the project station.
The type of hydrographic system (i.e. river, estuary, open ocean).
The distance between the project station and the controlling station.

Based on the best available information and indicators from the data collected in the New Jersey Marine Boundary Program, the tidal datums determined at the secondary control stations at Steelmanville 1 and Tuckahoe 1 have an accuracy of ± 0.10 feet for the 96-percent confidence level.

The accuracy of the tidal datums established from the data collected at the tertiary stations at Steelmanville 2, Steelmanville 4, and Tuckahoe 2 by the range ratio methods through the controlling secondary stations are considered to be ± 0.1 feet.

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DISCUSSION

Lt. Cdr. Floyd: How did you decide that the range-ratio method should be the standard: You said it was NOS' best method. How was that decided?

Mr. Hess: In the Borax case in 1952, it was decided that methods used by the National Ocean Survey are acceptable for marine boundary purposes. I think the range-ratio method was pointed out as the acceptable method for establishing tidal datums.

Lt. Cdr. Floyd: So it's accepted legally, and you want something as close to that as possible.

Mr. Hess: Exactly.

CIRCULATION AND HYDRODYNAMICS OF THE LOWER CAPE FEAR RIVER, NORTH CAROLINA*

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ABSTRACT. The results from the harmonic analysis of the data from tide and current stations in the lower Cape Fear River are presented in the form of tables, cotidal and corange charts, and charts illustrating the relationships among various harmonic constituents. Salinity and temperature data are presented in the form of contours of longitudinal transects and time series stations covering full tidal cycles. Instrumentation, data products, and the various methods of analysis are described. The implications from the results of the various methods of analysis of the circulation and hydrodynamics of the lower Cape Fear River are discussed.

A simple, one-dimensional model is presented to help describe the tidal hydrodynamics of a long narrow estuary. The nontidal rise and fall of the water surface of the river as a result of the meteorological forces of wind and barometric pressure is discussed. NOS historical data, a physical description of the area, and approximate values of transport through several cross sections are given.

It has been concluded that the tidal wave in the Cape Fear River is close to being a pure damped progressive wave with a partial reflection in the narrowing channel around Wilmington, N.C. The considerable amount of dredging that has taken place in the past 100 years has resulted in significant physical parameter changes. The flow regime in the Cape Fear River

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*This report is too extensive to include in these proceedings, but it has been published as NOAA Technical Report NOS 80. Paper copies are available for $9.00 from the U.S. Government Printing Office, Public Document Department, Washington, DC 20402 (stock No. 1979-281-067/247), and from National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Sills Building, Springfield, VA 22151 (accession No. PB80-117088). Microfiche is available from NTIS for $3.00 per copy.

is the result of gravitational effects caused by salinity intrusion, fresh water river flow, the river bathymetry, and channel structure. Salinity data indicate that the river changes from being partially mixed vertically to well mixed vertically as one progresses up the river.

DISCUSSION

Lt. Mason: You mentioned the tidal range has increased over the past approximately 90 years because of the dredging. Can we assume that this is due to the increased inertia in the system, and can that general statement be made about any system such as this in which you have dredging or increase of depth?

Mr. Parker: Essentially, because of the dredging there is a greater volume of water that can come in, and that's the basic reason why. You can generally say that it does happen. It happened in Boston Harbor as well. You'll also see the currents tend to slow up a little bit while the range is increasing.

Lt. Mason: Thank you.

Mr. Welch: Anyone else? Thank you.

PROCESSING AND ANALYZING TIDAL DATA ON THE INTERDATA 7/32 MINICOMPUTER

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ABSTRACT. The Interdata 7/32 minicomputer system purchased in late 1977 is expected to be in full operation by the end of 1980. Software is being developed in three phases: Phase I will store, list, and plot 6-minute tide data; Phase II will scan and edit 6-minute data, select hourly heights, find high and low waters using an interactive cathode ray tube (CRT), compute monthly means, and store data when completed; Phase III will provide additional capabilities such as simultaneous comparisons, break filling, and input/output methods. The present system is quite versatile now and will be given new capabilities. Are we including in our plans what the users of the tide data need? How can we better support automated hydrography?

The Tides Automation Project is, I believe, a rather open-ended project in which the software is developed based upon the hardware available. Our original feasibility study--already 3 years old--recommended a long-term data acquisition and automated processing system to meet existing and future needs. The study also recommended the development of an interim automated processing system which considers budget constraints and the time required to replace the present system. The Interdata 7/32 is this interim system. It is also likely to be the foundation of the long-term system because of money squeezes.

An Interdata 7/32 minicomputer system, purchased by the Tides and Water Levels Division in late 1977, was delivered in early 1978. We needed state-of-the-art hardware and software to process ever-increasing amounts of tidal data. The system has interactive and graphic capability and holds up to 16,000 station months of tidal data in various formats as a working data base. It also has a dedicated system. The software being developed for the Interdata 7/32 will replace the outdated software used with the IBM 1401, 360/40, and 360/65. The National Oceanic and Atmospheric Administration (NOAA) has replaced the IBM 360/65 and its Control Data Corporation 6600 with a Univac 1100/42.

The Interdata 7/32 has the following hardware configuration:

384 bytes of main core
two 9-track tape drives
three disk drives with 50 megabytes per disk

a console
six cathode ray tube (CRT) graphic terminals
two Versatec printer/plotters
a card reader
a paper tape-to-disk reader

In my opinion this system should have double the above hardware by fiscal year 1982 to meet the needs of the Tides and Water Levels Division.

What can it do?

(1) It will read in data from three sources: punched cards, Analog Digital Record (ADR) punched paper tape, and magnetic tape (the primary input source at this time).

(2) The software will take a large amount of data straight through to tabulations--an "automatic" feature that has been difficult to do on the IBM.

(3) It will plot 6-minute tidal heights by identifying the station and time period wanted. The plots are made on the electrostatic plotter and can be made for long series. Plots are also made interactively on a CRT terminal. The time period can be from 1 hour to 9 days in length. A copier attached to the CRT can make a light-sensitive copy of what is on the CRT. We can also make double plots on the CRT, plotting the same time period for two stations on the same axes.

(4) The new software will edit the data, flag bad spots, and fix certain types of bad data (if specified by the processor).

(5) Through batch or interactive mode it can produce completed tabulations of times and heights of high and low tides, hourly tidal heights, computed mean values, and selected extreme tides. These are output on either the electrostatic printer/plotter or on the CRT.

(6) Up to 16,000 station months of finished tabulations of hourly heights and high and low tides can be stored on disk.

(7) Mean values such as mean low water (MLW) or mean lower low water (MLLW) can be computed independently of calendar month. In the old system, means were computed only for complete calendar months of data. With ship or field parties unable to operate hydro stations only by calendar months, this was a problem in providing finished data for the survey. Now we can compute means for any time period we specify.

(8) Simultaneous comparision of monthly means of a control station and a subordinate station can be done automatically with data stored in the system. Hydrography needs the datum references that are derived from the simultaneous comparisons. A tide by tide simultaneous comparison has been developed, and we are beginning to use it.

(9) Data output is possible on CRT, in print or on magnetic tape.

At this time, the system cannot produce cards for hydrographic survey work. Since there is no card punch in the system, I hope that magnetic tape can be used as input at the marine centers for hydrographic processing.

The Interdata 7/32 also cannot provide for long-term storage of 6-minute heights. When a station month of data is completed, it is archived with the hourly heights and the high and low tides being held on disk. The 6-minute data are output onto magnetic tape for archiving on the IBM system now, and the Univac soon, I hope. Our long-term--more or less permanent--data storage is and will be on the "big" systems. Thus, the Interdata 7/32 system will not provide a data base for a large accumulation of data. At this time, it cannot be interrogated for data by telephone.

We would like to remotely access data with the Interdata 7/32 or the Univac 1100/42. For example, a marine center could call the computer and access specific hydrographic data. The marine center could receive the data by telephone onto magnetic tape, disk, or cards--whatever output form they could best use for their work.

We would also like to plot on any datum. At this time, our raw 6-minute heights are plotted as they are recorded without any adjustment for staff zero. We are developing routines for inferring with a high degree of reliability data that are missing because of a malfunctioning gage.

We are trying to procure a good state-of-the-art digitizer with which analog records can be converted to computer-compatible form and the data processed on the Interdata 7/32. If we can do that, perhaps the restriction for using bubbler gages for hydrographic surveys can be eased. Such a digitizer means, I hope, that all tide data can be available to users in computer-compatible form in the future.

The system is on the verge of being capable of many things. Phase III of the software development is due to be completed by summer 1980. We can continue program development as long as the need remains for the system to be more versatile. I would like your suggestions as to what the system needs to satisfy your requirements for processing tide data.

AIRBORNE LASER HYDROGRAPHY

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ABSTRACT. Airborne laser hydrography promises to gather relatively large quantities of accurate, inexpensive bathymetric soundings. In the past year, a systematic evaluation of airborne laser hydrography has been completed. Results are presented showing the benefits, performance, impacts, and the applicability of laser hydrography to National Ocean Survey surveying requirements. Major decisions on future involvement in laser hydrography are presented, along with the direction and status of present work.

INTRODUCTION

In 1970 the National Ocean Survey (NOS) recognized that an airborne laser system had the potential of performing accurate hydrography at low cost, and that it could be an appropriate technology for meeting the NOS survey requirements of the 1980's and 1990's. Since then, NOS has spent over $½ million in assessing the performance, benefits, and limitations of laser hydrography. Simultaneously, our work has helped to mature the technique, which has been developed to the point where a system suitable for NOS applications can be realized. Based on the information presented in this evaluation, NOS has decided to develop and implement an airborne laser hydrography system.

The laser hydrography system is an aircraft-mounted, scanning beam, pulsed-laser system weighing about 800 pounds. It measures depth exactly like a sonar, using light instead of sound. It takes between 400 and 600 soundings per second, with an average distribution of one sounding per 20 square meters (m^2)--that is, soundings are about 4.5 m apart in all directions. The depth of penetration is limited by water clarity, but 60 feet should be routine. It will operate day or night from almost any low performance, light, twin-engine aircraft. At an altitude of 1,000 feet and a speed of 150 knots the system can collect a 200-m wide swath of soundings along each flight line. The laser will be completely eye-safe for bystanders in the survey area.

BENEFITS

Four major benefits can be realized with the airborne laser hydrography technique: savings in cost, better use of personnel, capability of increased production, and a continuing improvement in the quality of our marine charting products.

Cost

A mathematical model was used to determine the cost effectiveness of laser hydrography compared to launch hydrography. It computes the cost per square nautical mile (nmi^2) using operating costs and amortized nonrecurring costs. The model's input parameters have been estimated and are shown in table 1. The total operating cost is $402,000 annually, assuming that all personnel and equipment are charged 100 percent to laser hydrography. The nonrecurring cost is $2 3/4 million.

The model combines these costs and performs such operations as adding an overtime/difficulty factor and annualizing the nonrecurring costs over the appropriate periods. The cost is then divided by the amount of area surveyed to compute the cost per unit area. Figure 1 shows the cost per unit area as a function of area surveyed annually. The best estimate of the cost of laser hydrography is $438 per nmi^2 at full use.

To determine the relative cost effectiveness of laser hydrography over launch/sonar hydrography, it was necessary to quantify the sonar costs. NOS made its own study and gathered results from many other studies. Using over 40 individual estimates for sonar costs, a combined estimate was developed. That combined estimate is a weighted average of the individual estimates where the weighting was by the amount of hydrography performed at each individual estimate. The result is $2,730 per nmi^2 as the best estimate of the operating cost of launch/sonar hydrography. When the sonar operating cost is compared to the laser total cost, laser hydrography has the potential of costing one-sixth as much as sonar per unit area when the laser is fully used. The cost comparison work was done for fiscal year (FY) 1977. In that year all 22 launches together surveyed about 1,600 nmi^2. At $2,730 per nmi^2, this hydrography costs about $4.3 million. If only one-half of the 1,600 nmi^2 surveyed by launch in 1977 were done by laser at a unit cost of $1,050 per nmi^2 (fig. 1), the savings would have been $1.3 million. The payback time for the laser would have been 2 years.

Laser hydrography has the potential of being more cost-effective than present methods of surveying by a factor of six. This ratio has a sufficient margin of economic safety for NOS to feel confident of achieving a significant cost reduction per unit area surveyed with the laser.

Personnel

The second way laser hydrography can be beneficial to NOS is through a savings in personnel. Significantly fewer staff years should be needed per unit of area surveyed than are presently required. The operating staff needed for laser hydrography was estimated using the same assumptions as the cost study and data from a separate study being made on airborne laser operations. Five people should be needed in the laser field party for full-time system operation. The amount of area able to be surveyed annually by laser was calculated in the cost-effectiveness study to be 1,920 nmi^2. Dividing this area by 5 staff years gives an effectiveness of 384 nmi^2 per staff year.

A nonrecurring requirement of 9 staff years is the in-house development

Table 1.--Parameters for determining cost effectiveness of laser system

Annual operating costs at full use	
Laser crew (3)	$ 75,000
Air crew (2)	50,000
Overhead	125,000
Travel	50,000
Laser maintenance	30,000
Aircraft operation and maintenance	72,000
Total	$ 402,000
Nonrecurring costs	
Laser system	$1,120,000
Hydrographic software	500,000
Positioning system	480,000
Aircraft	200,000
Development personnel	450,000
Total	$2,750,000

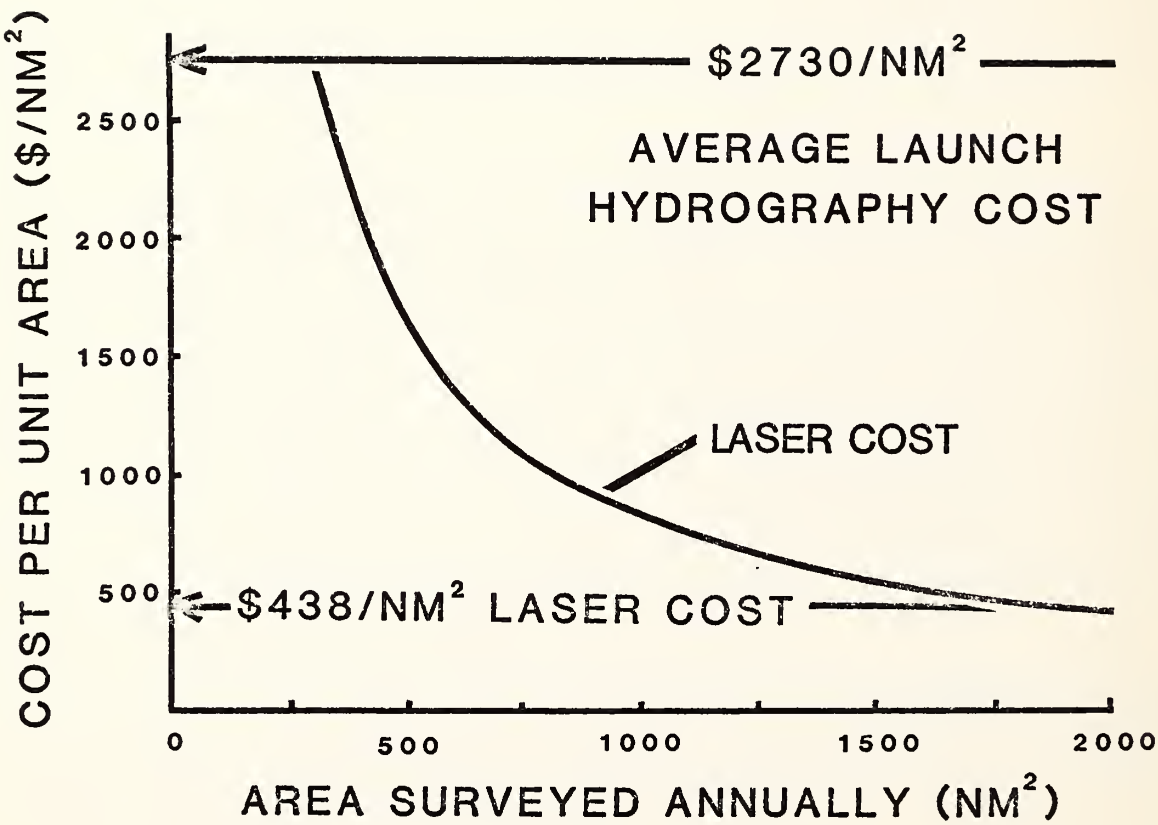

Figure 1.--Laser/Sonar cost comparison.

personnel needed to get the system into operation. It is analogous to the nonrecurring cost and is spread out over the life of the system in the same way. Spreading these 9 staff years over the appropriate periods gives 2,200 nmi^2 per staff year for development. The combined productivity; that is, operating plus developmental, is 327 nmi^2 per staff year for airborne laser hydrography.

To compare this with our present productivity, an estimate has been developed of the square nautical mile per staff year produced with launch sonar surveying techniques for FY 77. The all-launch weighted average for FY 77 is 57.4 nmi^2 per staff year. This is operating personnel only. The laser productivity, including both operating and developmental personnel, was 327 nmi^2 per staff year.

The ratio of the effectiveness of laser "total personnel" to the launch operating personnel is greater than 5 to 1. Therefore, the hydrography we now perform with 5 staff years of effort potentially can be produced by laser with less than 1 staff year.

In 1977 the launches surveyed 1,600 nmi^2 using 28 staff years of effort. If one-half of that had been done by laser, the total personnel used would have been 20 staff years, mostly for the launch. This would have been a savings of 8 staff years in 1 year. According to this computation, the laser would recover its development personnel costs in slightly over 13 months.

Since the relative personnel effectiveness of 5 to 1 for laser over launch sonar is large enough, NOS can feel confident of achieving a savings with airborne laser hydrography.

Increased Production

The third benefit offered by laser hydrography is an increased production capability. It was estimated that one airborne laser system could survey 1,920 nmi^2 annually. This is equal to 125 percent of the amount of area surveyed in FY 77 with all launches.

It is fair to ask if we need 1,920 nmi^2 of hydrography. Apparently, NOS needs at least 1,600 nmi^2 of it because that much was done by launch in FY 77. Since the launches worked their full year, it is felt that they would have kept going and surveyed more if time had been available. Therefore, if the 1,600 nmi^2 surveyed by launch and the 1,920 nmi^2 surveyable by laser are roughly comparable, one can say that there is a continuing need for the quantity of surveying which a laser produces.

Would NOS need 1,920 nmi^2 of surveying in addition to the normal annual launch production? It is difficult to answer the question quantitatively. Qualitatively, there does appear to be that additional demand. In a separate study, it was estimated that the NOS survey priority list, or 5-year plan, contains between 20 and 67 years of work. The inshore surveying in shallower water is already the work that gets deferred from year to year because of lack of capacity. Also, much of the demand for quick-reaction, high-priority work is in the inshore area which further defers scheduled work.

With the continuing increase in recreational boating, it appears that the need for inshore hydrography will continue to increase. NOS' traditional concern for human life and safety may require surveys in newly popular boating areas, more frequent resurveys of other recreational areas, and new charts at larger scales which, in turn, will require more surveying.

New initiatives and responsibilities may add to the NOS workload. In some cases the laser system may contribute directly, and in others it may contribute by releasing resources now used for inshore hydrography to handle the added work. These are examples of new initiatives and new responsibilities which the laser might help satisfy:

(1) surveying the trust territories,

(2) surveying fresh water areas,

(3) understanding and managing the coastal zone,

(4) providing larger scale charts of the Great Lakes,

(5) providing data for bathymetric-topographic charts for areas where existing data are insufficient,

(6) charting fishing obstructions,

(7) possibly helping the Defense Mapping Agency (DMA) keep their hydrographic production up, and

(8) expanding surveys because of increased vessel drafts.

It is felt, therefore, that there is sufficient work of importance to fully utilize a laser hydrography system. If added surveying capacity is needed, the laser would be the most cost-effective way of providing it.

Product Improving Potential

The final benefit to discuss is the way in which laser hydrography can help improve the NOS marine charting product.

The airborne laser will collect a significantly increased spatial density of soundings compared to sonar and with a much more uniform distribution. The problem of optimum density of soundings has been studied and a design value selected for the laser. That value calls for 300 times the number of soundings per unit area over what is now collected. This increase in data density is equivalent to starting with a 100-m line spacing and splitting the lines enough times to turn 2 lines into 20. This increased data density and more uniform distribution will provide a more representative picture of the sea bottom and will increase the probability that the shoalest depth is measured.

The way in which the system is used can also have an effect on the quality of NOS products. The laser system would be an ideal survey reconnaissance tool due to its high speed of survey, low cost, and the speed with which it

can commute among widely dispersed sites. With a better picture of where changes have occurred, one can schedule basic hydrography in the areas of greatest need. This rapid reconnaissance capability would be useful, for example, in the Gulf of Mexico after a hurricane, in Alaska after an earthquake, and along the east coast to assess changes due to winter storms before the recreational boating season begins in the spring.

The large amount of hydrography from one laser system can also help improve our marine charting product. Added surveying capability could be used not only to reduce the time between resurvey for critical areas, but also to release launches from production bathymetry so they could do specialized work like item investigation. More recent bathymetry and more item investigation would be useful to NOS in making a better product.

Summary of Benefits

The laser hydrography system is a highly cost-effective means of surveying. On a per unit area basis, it costs only one-sixth as much as launch hydrography. Equally important is that it only requires one-fifth as much staff per unit of area surveyed as launches require. The large survey production capability will help satisfy our present needs and give the flexibility to meet our growing responsibilities. More thorough sampling and the reconnaissance capability will help continue to improve the quality of our product.

PERFORMANCE

The performance of a laser system must meet the NOS standards for sounding accuracy of ±1 foot in water from 0- to 60-feet deep and position repeatability of within 1.5 mm at the scale of the survey.

Accuracy of Soundings

The bathymetric accuracy of laser hydrography has been investigated through a combined experimental and theoretical program. In 1977 field experiments were made using a NASA prototype laser system to measure the effects on performance of environmental and system parameters, to provide data for verification of performance models, and to make an accuracy intercomparison with sonar. Over 1½ million laser soundings were made during a 6-month period. The objective of the theoretical program is to model system behavior. The verified models will be used to extrapolate from the performance of the NASA prototype laser to the performance of the NOS operational laser and to explain observed experimental results.

Three terms are used to discuss the bathymetric performance of a laser. Two of these, precision and bias, are normally used to specify accuracy. The third term is profile correlation.

Precision is the random error in depth around the average depth. It is a measure of system noise and is a fundamental limit on the overall accuracy for a particular piece of hardware. We have modeled precision for the NASA hardware as part of our theoretical program (fig. 2). The model shows poor precision at low signal-to-noise ratios and a rapid improvement as the signal-to-

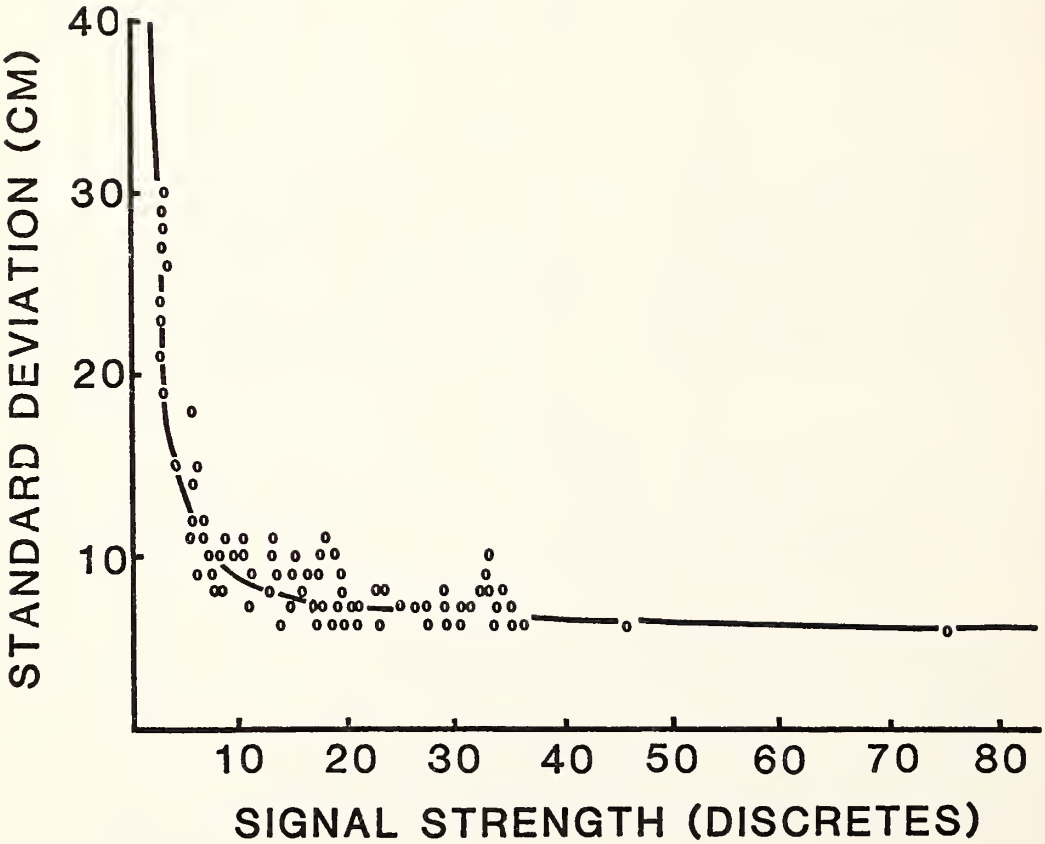

Figure 2.--Bathymetric precision vs. signal strength (experimental).

noise ratio increases. A saturation value of about 5 centimeters (cm) is predicted. This saturation value is what we expect to see in the experimental program.

The experimental data do indeed agree with the theory's prediction. The characteristic dependence on signal to noise is present and saturation is achieved at 10 cm. Because experimental results are in good agreement with the model, it is felt that system precision is well understood. The NOS system can be designed so that the random errors in depth are a small fraction of the total error budget.

The second measure of performance is bias. Bias is the constant offset between the measured depth and the true depth. Since the true depth is not known, an intercomparison was made between laser-measured depth and sonar-measured depth (sonar being the standard, accepted technique). Thus, one does not actually measure laser bias, but laser/sonar differences.

In such an intercomparison, one does not expect to see perfect agreement between the two systems, because error can be contributed by both systems. It is possible, however, to predict what agreement should be seen using an error budget. An error budget has been produced for the laser/sonar intercomparison in order to estimate what differences one expects to see experimentally. Four sources of error have been identified: error due to the sonar, depth errors caused by mispositioning soundings, errors caused by interpolating tides from the gages to the test site, and errors in the laser measurement of depth. Values have been assigned to each of these error sources and then combined to produce the expected laser/sonar difference.

This error budget technique can also be worked backwards. If one knows the observed laser/sonar difference and the values of all but one error source, then the magnitude of that remaining error source can be computed. This was done using the experimental result (8.2" ± 5" average laser/sonar difference) and the estimated sonar (3" ± 2"), positioning (4" ± 2"), and tide (1" ± 0") errors to compute what the laser accuracy must have been. The result is that 6.4" ± 4" is the best estimate of system accuracy for the NASA prototype laser system.

This is a very encouraging result. The system tested was first-generation hardware designed for research not accuracy. The software was a prototype research tool. No sophisticated data processing has been done to improve accuracy other than wave correction and the depth extraction algorithms. By continuing to evaluate the data and by developing more intelligent algorithms, the laser should be at least as accurate as the sonar.

The third facet of performance is profile correlation. This is a measure of whether the laser and sonar are consistently seeing the same bottom. Profile correlation is measured by removing the constant laser/sonar difference and compiling statistics on the residual differences. This residual difference is expected to have a standard deviation of less than 10 cm. The experimentally observed standard deviation is indeed on the order of 10 cm and it is thus felt that laser and sonar consistently see the same bottom.

To summarize the results on sounding accuracy, it should be restated that the NASA laser is now measuring depths to within 6.4" ± 4". It is probable that this can be improved through the use of hardware designed for bathymetry and improved software. A system which can repeatedly measure depths to within the NOS standards is therefore a realizable option.

Positioning

Our goal is to be able to meet the positioning standard specified in the Hydrographic Manual; i.e., that the repeatability of a position fix shall seldom be worse than 1.5 mm at the scale of the survey. To position accurately enough for the 1:5000 scale survey--the largest scale done with any regularity by NOS--means being able to repeat a position fix within ± 4.5 m root mean square (rms).

An error budget has been developed to study positioning accuracy that accounts for errors in locating the aircraft, errors in aircraft orientation, errors in the laser pointing direction, and so forth. The individual components of the budget were estimated using the NASA prototype system parameters and industry experience. The result is that of the ± 4.5 m total positioning error, fully ± 4 m can be allocated to positioning the aircraft in the sky.

To determine how close we could come to the ± 4 m, we identified several positioning systems as candidates and investigated their accuracy. For one system, the Cubic Autotape DM 43, the following test results were available: In 1975, the Applied Physics Laboratory of Johns Hopkins University measured the accuracy of a ship-mounted Autotape DM 43 using theodolites as the reference measurement. They found that the two systems agreed to within ± 4.6 m for 214 fixes. This ± 4.6 m includes errors due to both the autotape and the theodolites plus the error due to geometric dilution of position (GDOP).

The second test of the Autotape DM 43 was performed in 1978. In that test, an aircraft-mounted system was used to determine the separation of two offshore oil platforms using the baseline crossing technique. Satellite doppler observations of the actual platform positions were made for ground truth.

Test results showed that the autotape measurement agreed with the satellite measurement to better than ± 0.4 m. The distances, aircraft speed, and altitude in this test were very similar to those anticipated for the laser system. These results indicate that the autotape is potentially capable of providing the required aircraft positioning accuracy.

This examination of positioning systems is limited. It was done so this evaluation would be more comprehensive. A significant amount of work will be performed during the development project to produce the solution that will be implemented.

APPLICABILITY

A laser system must be capable of meeting the survey needs of NOS. What

one needs to know is the types of areas which could be surveyed, how much surveyable area there is, and are those areas of interest to NOS. Since the laser is an optical technique, its ability to survey an area is determined primarily by water clarity, depth, and the laser system parameters. Bodies of water have been studied where water clarity and depth information were both available. Using the design goal parameters of the NOS laser system, estimates were developed of the amount of each area which could be surveyed by the NOS laser. Results from several of these areas are available.

In the open water area of the southern Chesapeake Bay, it is estimated that NOS could survey at least 80 percent by laser under average autumn water clarity conditions. The surveyable region covers the entire near-shore area, most of the body of the Bay, with only a few of the deeper channels indicated as beyond the reach of the NOS laser system. Typical depths being reached are 30 to 35 feet--well into the region of safe operation for high-speed launches.

These estimates were prepared using discrete measurements of water clarity taken over 15 years. The data were averaged over the 15 years for each season and then contoured. Combining the water clarity contours with depth from NOS charts, those areas where the NOS laser system would be able to penetrate were determined.

The James River area was also examined. It is estimated that NOS could survey by laser at least 65 percent of the lower section of the James River under average summer water clarity conditions.

These estimates are for seasonal <u>average</u> water conditions. There is every reason to believe that a larger percentage could be surveyed by flying hydrography when water clarity was better than average. Because of the high speed of airborne laser surveying, that "window" need not be long.

A third area is Tampa Bay. The Tampa Bay estimate was produced by extrapolating from aerial photographs instead of using discrete samples of water clarity. In 1976 the Photogrammetry Division examined a series of aerial photographs and marked areas where bottom was visible. One can extrapolate from the photo-surveyable area to the laser-surveyable area using the relative penetrating ability of the two techniques. Most such photo-extrapolated estimates were corroborated by DMA or NASA using satellite imagery. Using aerial photography, Tampa Bay is estimated to be 100 percent surveyable by laser. The maximum depths in the Bay of 35 feet are easily within the capability of the NOS system.

In a region of the Gulf of Mexico just north of Tampa Bay, a photo-extrapolation into the body of the Gulf was made and corroborated with LANDSAT imagery. Between Anclote Keys and Crystal River depths of 70 to 100 feet are surveyable. This translates to distances as great as 40 to 60 nmi from shore. Data were not available outside the indicated area.

One final area where aerial photography was used was in Nantucket Sound. Essentially all of Nantucket Sound should be surveyable by laser. Depths of 60 feet should be routinely reached in the Sound itself and 90 feet or more

in the ocean.

It has also been possible to secure discrete measurements of water clarity for the Great Lakes, starting with Lake Ontario. These measurements of water clarity were acquired from the Environmental Protection Agency (EPA) data bank. It is estimated that 35 percent of Lake Ontario could be surveyed with the NOS laser system under average autumn water conditions. Since Lake Ontario is very deep, reaching 600 and 800 feet, this large open area is slightly out of reach.

Data were also available for Lake Huron and Lake Erie. An estimated 55 percent of Lake Huron can be surveyed by laser, reaching depths in excess of 130 feet. An estimated 65 percent of Lake Erie should be surveyable with the NOS laser system under average spring water clarity conditions. Depths reached in the middle of Lake Erie are expected to be in excess of 60 feet. The shallowness of the lake allows a large percentage to be penetrable by laser in spite of poor water clarity.

Lake Erie's reputation for being polluted demonstrates that a body of water which is chemically intolerable need not be optically opaque. Chesapeake Bay is actually worse than Lake Erie. This is because the Bay has a high sediment loading, heavy traffic, shallow depth, and a great urban and agricultural runoff.

One final area where an estimate was made was New York Harbor. Based on sparse data, 70 percent of the lower Bay should be surveyable under average autumn water clarity conditions. This is somewhat deceptive, since the greatest depths in the lower bay are only 23, 24, and 25 feet.

Four general results come from this work. First, laser hydrography can be used in a wide variety of areas. Results have been determined for the Gulf of Mexico, for the Atlantic Ocean and typical east coast sounds and estuaries, and for the Great Lakes--the entire spectrum of east coast areas.

Second, large amounts of area appear to be surveyable by laser. It was shown that 80 percent of southern Chesapeake Bay, 70 percent of New York Harbor, 65 percent of Lake Erie, all of Tampa Bay, and 95 percent of Nantucket Sound should be within the surveying capability of the NOS airborne laser hydrography system. This puts an impressive amount of area within range.

Third, the technique can <u>routinely</u> penetrate to depths required for safe operation of the high-speed launches. It can <u>frequently</u> penetrate to depths required for the safe operation of our hydrographic ships.

And fourth, laser bathymetry can be performed in areas where NOS has ongoing survey priorities.

Thus, airborne laser hydrography is not a special-purpose technique, but a highly useable production tool capable of contributing large amounts of surveying to the NOS hydrographic effort.

OPERATIONS

Laser operations were studied to see that the projected cost and personnel savings would remain after the practical aspects of laser surveying were considered. Such a study would also help identify potential impacts of an airborne laser system. Two sources of information were used for the study of laser operations: an operating scenario and the experience gained from the 1977 laser field tests.

The operating scenario was a study of a laser survey which laid out the steps to be performed and examined, each in turn. A specific geographic location was picked as a study area to provide site-specific parameters. Examining operational steps for a specific location enforced realism, attention to detail, and a quantitative approach.

The chosen study site was an area on the eastern side of the Chesapeake Bay centered around Crisfield, Md. The survey boundary enclosed 750 nmi^2 of which 500 nmi^2 is water. While 450 nmi^2 of the 500 nmi^2 of water is expected to be surveyable by laser, the remaining 50 nmi^2 probably has to be surveyed by launch. The 260 swaths of laser hydrography needed to survey the laser area would overlap by 20 percent. An estimated 100 hours of flight time over the area would be needed for the survey. Since 100 hours is about one-third of the annual capability of a laser system, the elapsed time would be around 4 months (about 6 hours per week). The launch subarea would take an estimated 7 months for a single launch.

Several things were learned from this scenario. Some categories of hydrographic support work will scale with the size of the area independent of the survey method. Tide control, field edit, and Coast Pilot work are examples of this. Other types of hydrographic support, such as positioning, increase slower than the size of the area. This entire survey site could be covered with three, shore-based transponders.

Management tools needed to effectively operate the laser system were identified through development of the scenario. Examples of such tools are mission go/no go criteria based on water clarity, the point at which it is no longer cost effective to survey a winding river, and what to do with holidays in the survey. Each time a tool or criteria was needed for the scenario, one was developed which would be suitable for use by a laser survey party. Thus, the laser does not appear to require hard-to-get information to control effectively.

The other look at laser operations was during the 1977 experimental program when the NASA prototype laser system was field tested. Over a 6-month period 18 missions were flown that collected one-and-a-half million soundings. All missions were successful except once when the laser hardware failed. This means that we were consistently able to gather necessary information on water clarity and weather, provide operational logistics, establish positioning and tide control, and coordinate a laser surveying effort.

The results of this study of laser operations indicate that the difficulty of planning and executing a laser survey is probably between the difficulty of a launch survey and a photogrammetry mission. The practical aspects of airborne laser hydrography did not require degrading system performance below the point of economic return. The impacts identified through this study were primarily of secondary importance and usually affected only the field party. The conclusion is that the airborne laser is an operationally manageable tool.

IMPACTS

Any new process or technology can affect an organization. Because the impacts can affect the desirability of airborne laser hydrography, it is appropriate to include them in an evaluation of the technique.

The main impact of airborne laser hydrography will be the reduced cost and personnel required for hydrographic surveying and the much more thorough sampling of a given area. These highly beneficial effects were discussed earlier. The laser system is capable of doing a lot of bathymetry and, to operate in the most cost-effective way, it should be fully used. How this production potential is used will determine where the impact is felt. If it is used to increase the total amount of surveying, then the impact will be in chart production. More new and updated charts will be produced from the increased surveying and NOS will want to be sure that the chart production organization is capable of applying the additional data.

NOS could decide to capitalize on the cost and personnel savings instead of the increased production. This could be done by replacing launch surveys with laser surveys and would free the launches and launch personnel for other tasks. The impact would be felt as a shift in the "typical" responsibilities of the launches. Capitalizing on the potential savings in personnel could be an effective way of maintaining hydrographic capability while suffering the incessant staff reductions looming in the 1980's.

Another potential impact of laser hydrography is financial. It will take a capital investment in order to realize the cost savings in operations. Where NOS finds these funds will determine where the impact will be felt.

A third potential impact is in data reduction, processing, and verification. The uncontrolled collection of bathymetric soundings by laser could quickly overpower NOS at any number of points in the chart production system. This was recognized early and steps are being taken to control such an impact.

The system is not simply a piece of hardware. It is a complete data acquisition and processing system. The key to making the system work effectively is the sophisticated package of hydrographic software which comes with it. The hydrographic software is a highly automated data processing subsystem which will manage the data, perform the quality control steps, and produce an optimum output.

Implicit in this argument is that NOS be willing to continue evolving to more and more automated data processing and data management. Laser hydro-

graphy is a natural evolutionary step from the present work in large data base systems such as the Automated Information System and the Bathymetric Swath Survey System.

A fourth area of impact will be in field operations. This new tool will need new management techniques and new operating skills. Scheduling will be different, the information provided for data quality and completeness assessment will be different. These changes will require training and adjustment.

Laser operations will also cause an impact in launch operations. Less launch work will be performed in shallow water. Since less basic hydrography would be performed by launch, launch responsibilities can be shifted to specialty work such as item investigation.

These five areas then are where we see the greatest potential for impact:

(1) cost and personnel savings,

(2) increased amount of hydrography,

(3) the investment cost,

(4) data processing, and

(5) hydrographic field operations.

Some of these are beneficial impacts. None of them have unacceptable consequences if they are planned for in advance.

CONCLUSIONS AND RECOMMENDATIONS

From this evaluation of the airborne laser hydrography system we have made these four conclusions.

First, airborne laser hydrography offers NOS the significant potential benefits of cost and manpower savings, increased production, and high product quality. On a per-unit-area basis, it should survey for one-sixth the cost and one-fifth the personnel of our present launch/sonar. One laser system should produce more hydrography than 22 launches did in FY 77. The laser's ability to sample more densely and more uniformly than sonar should help provide a marine charting product which is more representative of the bottom.

Second, an airborne laser hydrographic system can be built which will perform to NOS accuracy standards. Both the accuracy of the soundings and the accuracy of the positioning have been investigated and the NOS standard is expected to be achievable.

Third, airborne laser hydrography can be performed at a wide variety of sites where NOS has survey priorities. It is not a specialty tool but should be able to survey a tremendous amount of area.

Fourth, no unacceptable impacts of airborne laser hydrography have been identified. Potential impacts which have been identified can be minimized through planning.

Based on these conclusions, it was recommended that NOS should proceed with the development, acquisition, and implementation of an airborne laser hydrographic system.

PRESENT WORK

After considering this evaluation of laser hydrography, the Director of NOS and the Associate Director for Marine Surveys and Maps decided to proceed with the implementation of an operational system, and a 5-year development plan has been prepared. Figures 3 and 4 show the estimated time and cost required.

The needed funds have not yet been produced, but work has begun where possible. The laser hydrography system has been divided into three major subsystems plus an aircraft. Figure 5 is a schematic of the system with the data interfaces identified. Work is presently being done on the positioning subsystem and the hydrographic software/data processing subsystem. Additionally, continuing scientific analysis is being performed on the laser sounding process.

A more thorough analysis of positioning errors has been performed. Locating the aircraft in the sky still remains the largest single error. The next most difficult error is aircraft heading. Heading will affect where the laser beam hits the water and thus the position of the sounding. It now appears that the only acceptable solution to determining heading accurately is to incorporate a complete inertial measurement unit as part of the positioning subsystem. This inertial unit would operate with a microwave positioning system, or possibly, with the satellite Global Positioning System to measure the six degrees of freedom of the aircraft.

The present work on the positioning subsystem is the preparation of a Request for Proposals (RFP) and procurement package. The functional specifications that the system must meet are being determined and documented. The actual selection of a positioning system will then be from among contractor responses to the RFP.

The hydrographic software/data processing subsystem is being designed from back to front, that is, the final products of a laser survey are being defined first. Once the final products are agreed to, the subsystem can then be designed to provide them. A series of intermediate survey products are also being defined. These products are for the hydrographer in the field to use in evaluating the completeness and accuracy of a laser survey. They will serve a function somewhat analogous to the field sheet. When an agreed upon set of intermediate products are defined, the subsystem can be designed to provide them. Data processing hardware will not be specified until all the data products and necessary software are well established.

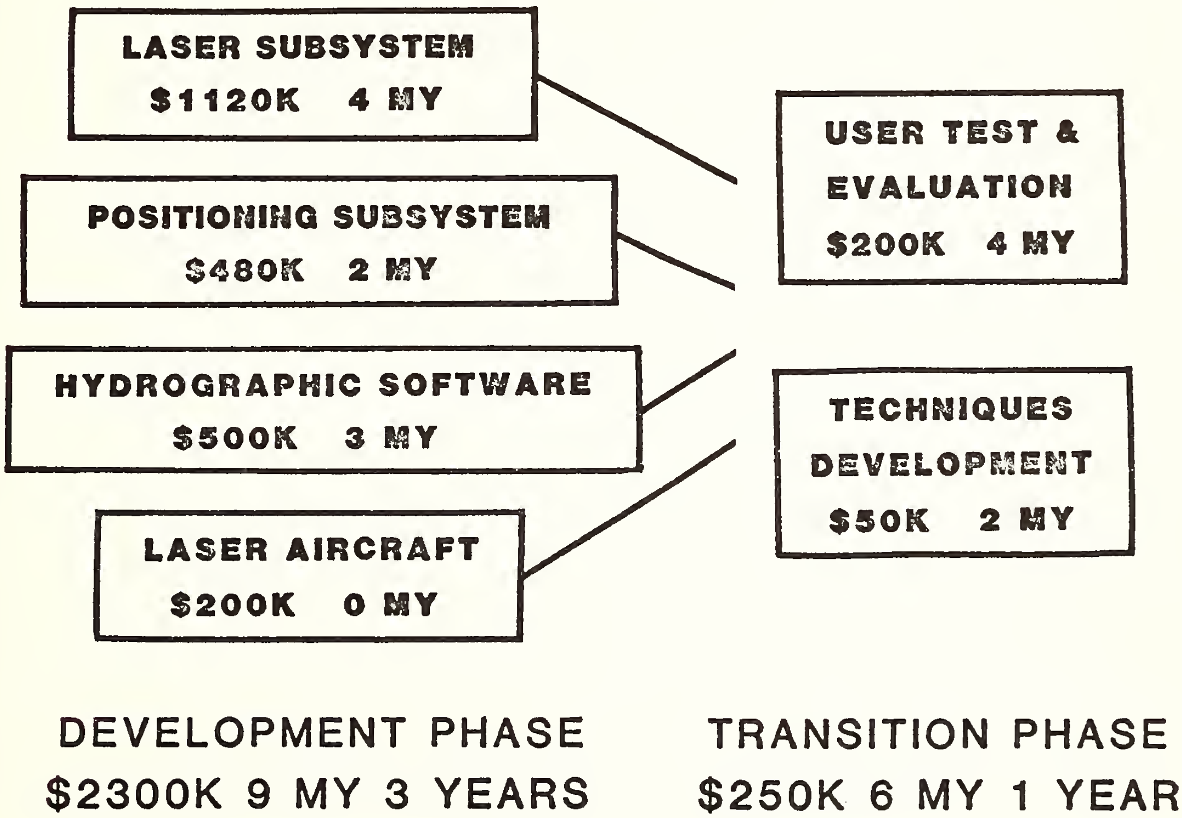

Figure 3.--Laser hydrography implementation plan.

	FY80	FY81	FY82	FY83	FY84
LASER	20K	25K	510K	565K	0
POSITIONING	90K	245K	145K	0	0
SOFTWARE	155K	198K	95K	52K	0
AIRCRAFT	0	0	0	0	200K
TOTAL	265K	468K	750K	617K	200K

OVERALL TOTAL $2300K, 9MY

Figure 4.--Laser hydrography implementation plan.

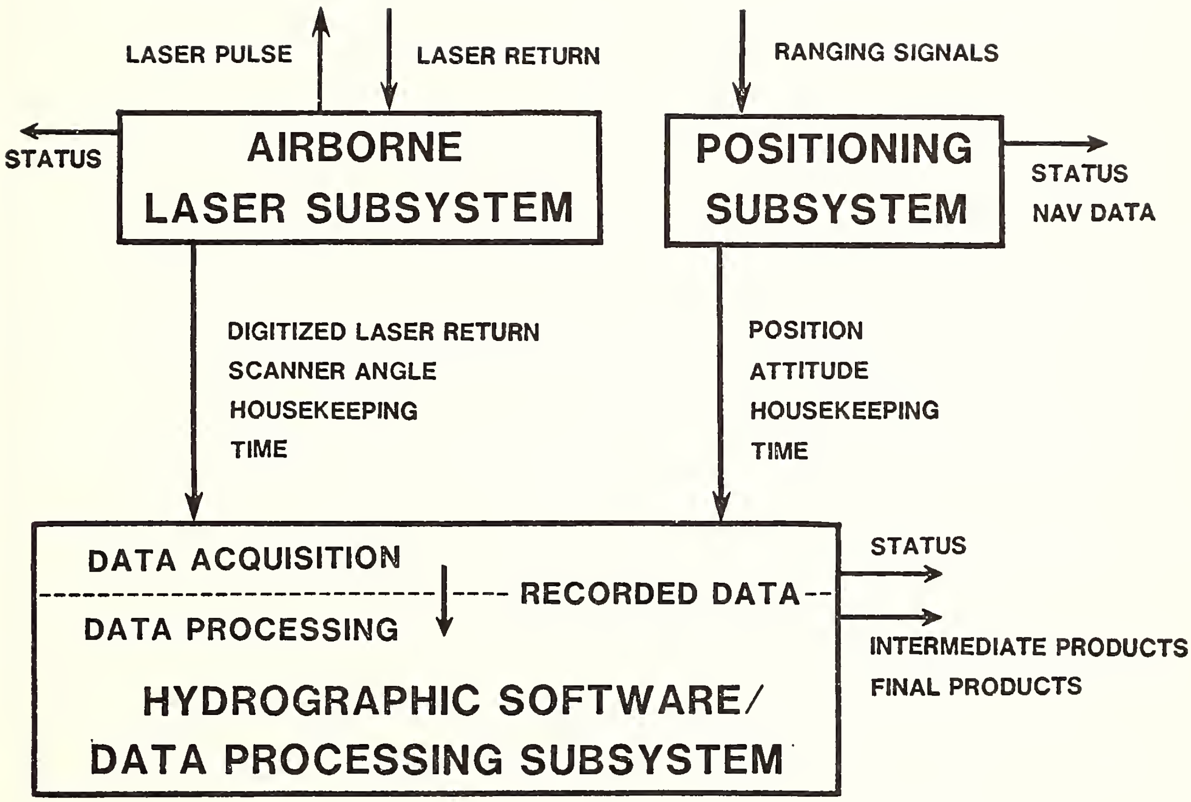

Figure 5.--Hydrographic software/data processing subsystem.

Work is proceeding also in the scientific analysis of the laser sounding process. Two computer simulations have been created. One simulation models the propagation and distortion of laser sounding pulses. The results of this simulation will allow improved sounding accuracy by removing propagation-induced biases. Pulse stretching is one such distortion that will produce a bias. The other simulation models errors in determining depth caused by the receiver electronics and the depth determining algorithm. Depth jitter caused by additive noise is an example of these errors.

Budgetary and procurement problems are the most difficult ones faced by the project. The system is being developed in a few, large pieces and funding must be available in a few, large pieces. The rational development of an airborne laser hydrography system cannot proceed with small infusions of cash at irregular intervals.

DISCUSSION

Mr. Carstens: What would be the sources of anomalous data? Would grass show up as anomalous data and could you identify it by your system?

Mr. Enabnit: The question concerns depth anomalies--what do we do with them, what causes them, and how do we identify them? Let's categorize anomalies as two types--the ones induced by the system and laser sounding process, and the ones induced by the environment.

We intend to take care of the system's anomalies through scientific analysis and careful development. We will be able to produce a document which says that these are the tests we performed, the tests meet the standard accepted practice of the engineering profession, and that this system is qualified. This is what the lawyers like to have when they go to court.

The other types of anomalies are the ones induced by the environment. The laser system will see the optical bottom. If there is grass and kelp there and it forms a canopy, we will see the top of the canopy. That is, as you well know, not the true bathymetry. Similar problems exist with sonar. That's a fact of life. That's the way the system operates. It's not a silver bullet. I wish it were.

We do intend to have indicators within our data processing system which allow us to ask questions such as how does the depth change at this spot with respect to nearby spots? Then, if I suddenly come upon a canopy of vegetation, I will be able to identify that as an anomaly and flag it so that a hydrographer can determine what to do about it. Do I go back out there with the laser system? Do I go out there with hip boots and look for kelp?

Does that answer your question?

Mr. Carstens: Good enough.

Lt. Chelgren: How does it see things like wood pilings?

Mr. Enabnit: There is a statistical chance of actually putting a sounding on a piling. This probability is much larger than with sonar. The question of being able to identify that piling within an individual sounding, however, has to do with the optical cross section of the piling. Does it reflect enough energy so that you see it instead of the subsequent energy reflected from the bottom? We do not know. We are not touting this as a system to investigate specific hazards to navigation. We're not using it as an item investigating tool. That is an application which we have not yet addressed with the research we're doing. We certainly would like to. I have no answer for you today.

Lt. Cdr. Floyd: You mentioned using this system for reconnaissance. It occurs to me that once you get the system set up in the field, the actual running of the hydrography would take no time at all. Why use it for reconnaissance? Why not just run a whole survey? It seems to me it would be ineffective used as a reconnaissance tool.

Mr. Enabnit: You're asking about operational criteria to decide between running a reconnaissance survey and running a basic hydrographic survey. I can see that it makes it much more attractive to say that if there is a difference of 6 inches, we should do the whole survey. This will be an operational decision as to how you employ it--it would indeed be cheaper to go ahead and run the full survey than it would have been to run the full survey with launches. Does that address your question or do you want to add something?

Lt. Cdr. Floyd: My point was that it usually takes so much time to set up your navigation stations and get set up to run the reconnaissance that once that work is done, it would only be a small added effort to run the entire survey.

Mr. Enabnit: Oh, I see your point; okay. It could take you 4 days to do the survey, and 4 days to set up for a 20-minute reconnaissance. So the cost is about the same both ways.

Lt. Cdr. Floyd: Right.

Mr. Enabnit: Okay.

Lt. Cdr. Floyd: And then maybe a whole day just to run the whole survey.

Mr. Enabnit: Well, if that's the case, then I would recommend running the whole survey. And one of the things that will be developed, of course, is a chapter in the Hydrographic Manual which says, this is the way you use the system, and such criteria should be easily developed. There's a tradeoff there to make, clearly. If it's 4 days to set up and if the added time to do a complete survey is 10 percent of the total time you're going to be in the area, well, just do the survey. You're right.

Lt. Cdr. Floyd: Do I have the wrong impression?

Mr. Enabnit: I think there is a tradeoff there.

Cdr. Pfeifer: I have a comment to offer on this. Unless you are going to have a breakthrough with the satellite positioning system, the ground support for the positioning system that you will need is not inconsiderable.

Mr. Enabnit: But it will not be any more than you are already incurring with the launches.

Cdr. Pfeifer: Yes, it will be, because you are dealing with a much faster-moving platform, and with topography which has to be taken into consideration. You are going to cover a much wider area with the same system.

Mr. Enabnit: That's correct.

Cdr. Pfeifer: So you have a greater problem. My comment is that a reconnaissance survey perhaps could be run just on the inertial navigator.

Mr. Enabnit: That's a good point.

Cdr. Pfeifer: Bypass the need for shore stations.

Mr. Enabnit: Calibrate at the airport and use the inertial navigator. You are doing the reconnaissance in less than half an hour. I think the drift rate for these inertial systems is a tenth of a nautical mile an hour for a high quality one.

Lt. (j.g.) Rulon: It depends on the expense of the inertial system.

Mr. Enabnit: Between a tenth and 1 nmi an hour? That may be more than sufficient for reconnaissance capability. Thank you.

Mr. Westbrook: Ladies and gentlemen, I think we're running overtime here a little bit. I hate to cut off the questioning. It's a very interesting subject. Thank you very much, Dave.

THE HYDROGRAPHIC MANUAL--AN UPDATE

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ABSTRACT. A concentrated effort is being made to maintain the National Ocean Survey Hydrographic Manual through the periodic compilation and distribution of "changes." These "changes" contain corrections ranging from misspelled words or misplaced punctuation marks to updated technical material required to keep the manual current with respect to changing technology. Other points covered include the importance of registration; official distribution; current stock of the Hydrographic Manuals; and the need for, and importance of, review and comment on published material.

All of you, I hope, are familiar with the National Ocean Survey (NOS) Hydrographic Manual, Fourth Edition (Umbach 1976). I have read this manual page by page several times, and, although I still cannot quote it in many instances, I am thoroughly convinced we have an excellent "bible" for hydrographic operations. The manual has been distributed from Tel-Aviv to Tokyo and from Singapore to Sweden. The Naval Oceanographic Office is in the process of adapting this fourth edition instead of updating or rewriting their old manual. As Don mentioned Tuesday, a working group met this past year to discuss ways in which the fifth edition might be written and published as an NOS/NAVOCEANO cooperative venture. The fifth edition is, however, many years down the road.

Our most immediate problem is in updating the fourth edition. After the manual was authorized for use on March 20, 1978, numerous errors in spelling and punctuation and many omissions were discovered. In conjunction with these corrections, a request was sent out for text covering technology not available at the time the manual was compiled 2 years earlier. As a result, text was compiled, illustrations were prepared, and constant liaison was maintained with the affected program areas. After numerous checks were made and comments were considered, Change No. 1 was submitted the first week in November 1978, through the Department of Commerce (DOC) to the International Computerprint Corporation (ICC) for photo composition. To say delays were encountered is a gross understatement. We received camera-ready copy page proofs, but they were far from being ready for the camera. We soon discovered that in correcting one error, the contractor created others. This should not have happened because the contractor was supposed to have had a master drive tape. Finally, during the first week in April, Lt. Cdr. Donald L. Suloff and I

drove to Fort Washington, Pa., and carefully went over the latest camera-ready copy. We were to return that day with the final version plus the master drive tape. After several hours of working with ICC personnel, Don and I received a cut-and-paste version of camera-ready copy. Unfortunately, their main computer broke down that day so we had to be content with the cut-and-paste and no master drive tape. We were promised a tape the next week. It still has not arrived in Commerce as of this morning. The Change No. 1 copy was delivered to the Commerce Composition Division and ultimately to GPO. Then the fun really began. Although the original manual printing and binding requirements called for top quality in everything, GPO submitted our Change No. 1 for low bid, quick and dirty printing. Needless to say, that's exactly what we got.

The July printing was totally unacceptable. Some of the problems included misaligned and mispunched holes, some of which had gone through text, continuous tone photographs were treated as line drawings, and text was washed out. In addition to washed-out photographs, there were inconsistent margins--I could go on and on. We did not have to convince Commerce. During the meeting called to discuss the problem, Commerce began telling us in more sophisticated terms what was wrong and why we should not accept the job. To cut short this type of discussion, we were finally able to get copies of Change No. 1 available and released for distribution to you on October 4, 1979; almost 1 year after input was submitted to the contractor.

I don't intend to go into the problems associated with Change No. 2, but I will say the input was given to the contractor on August 3, 1979, and we are not yet at the acceptable camera-ready copy stage. In other words, things don't look any rosier than they did for Change No. 1. Change No. 3 is still in the file folder stage.

This tremendous time delay has resulted in some policy not being transmitted to you in a timely manner. We have been trying to solve the problem, and we may ultimately furnish major field units with copies of the final draft input to be used as interim guidelines. This will, of course, add another multiple copy, multiple page xerox job in our office, but we can see no alternative. We need your input for update of the manual. You need the authorization to use the input. I have been told by several of you that you would rather not submit input for, say Change No. 2, until you have been able to digest what was used from a previous submission (like Change No. 1). We can understand your feelings, and we also appreciate your having sent the input when it was called for, or when you felt you had something that would improve the manual.

To make the Hydrographic Manual a continued success, we need your continued cooperation. We need to have you monitor and evaluate old as well as new technology and to submit recommendations for improvement of the manual as a guide in using this technology. We have received excellent response when we have asked for it, and in several instances your efforts have been outstanding.

I especially thank Rudy Sanocki--AMC Processing, and Pam Chelgren--PMC Processing, but formerly Operations Officer on the Ship PEIRCE. Each of

these people sent in several pages of very significant material. It is quite obvious to us that these two people have not only studied the manual but have done so in such a manner that each will greatly benefit professionally.

We receive information in many ways. As a result of discussions held at the Hydrographic Conference last year in Seattle, Wash., NOS began to look into the question of accuracies required in hydrographic surveying. Many of you may recall receiving a memorandum/questionnaire from me asking for your personal and professional opinion of the published NOS requirements--specifically those in table 4-4 on page 4-36 of the Hydrographic Manual. A general concensus revealed that our accuracy requirements for hydrographic surveys were satisfactory for the present. Also, accuracy standards are being questioned in international circles. Specifically, Captain Ayers from the International Hydrographic Organization (IHO) and our own Capt. Wayne Mobley, recently on the staff of the Office of Marine Surveys and Maps have exchanged several letters which brought out the fact that this is indeed a question of international significance. It is my opinion that the subject will be brought up at a future meeting of IHO or The Hydrographic Society, and that it will be resolved by a working group, which, hopefully, will include NOS representation at a high level. These discussions can have a great effect on the manual. The Hydrographic Surveys Division would appreciate receiving copies of any correspondence which concerns this question of accuracies or which could cause even minor changes in the manual.

A major problem came to light when we distributed Change No. 1: the registration of the manual, or rather, the lack of it. There were 1,600 manuals printed,and as of January 10, 1980, only 415 copies had been registered. We do not know, however, how much stock is left at GPO, or how many copies they sold which remain unregistered. We do know that considering the small stock in NOS and that many manuals issued within NOS are not registered, only 25 percent of the manuals on issue worldwide are registered. This is very regrettable, especially when a manual must be registered if the changes are to be received. A manual which is not maintained with updates should be discarded! It could provide erroneous guidance. For your information, Change No. 1 contained 70 sheets or approximately 140 pages. Change No. 2 will contain approximately 100 sheets or 200 pages, many of which replace pages of Change No. 1.

Some of you have pointed out to us that you could not detect some of the changes. To alleviate this in the future, we plan to use an asterisk, a star, or a bar to indicate new or changed material, regardless of whether it is for an incorrect punctuation mark, a misspelled word, an omission in text, or for new material.

We also need your help in keeping manuals in the office to which each was assigned. Manuals are not registered in the name of an individual unless that manual was purchased from GPO. NOS has not officially issued copies to individuals in NOAA, although a very few presentation copies were made. Some copies were also presented to commercial firms, and domestic and foreign governments where it was felt this could enhance the quality and/or standardization of hydrographic surveying worldwide.

It was discovered during distribution of Change No. 1 that many manuals were no longer in a specific office but were packed and forwarded when people were transferred. It is these manuals which will probably be outdated very quickly because they were removed from the assigned area, and the change might not catch up with the manual. If you know of such instances, please use your influence to have the manuals returned. If an office exists which was not furnished a copy, and a copy _is needed_, we do have a small number left in stock. We realize this is a problem for which there is no quick or easy solution. Many of you here today have probably treated the manual in your possession as your own, by putting in your own personal explanatory notes. The question then arises as to what should happen to that manual when you are transferred. Almost all of us here would take the manual with us. But if you do, please let us know. We are not against your having a manual if you need it--we are against your having an _outdated_ manual. I might point out, though, that we _do not_ have enough copies for every Dick and Jane, Tom and Mary in NOAA.

It is only fitting that a discussion of the _Hydrographic Manual_ be used as part of the closing for such a conference as this. We have discussed horizontal and vertical control, photogrammetric procedures, tides/water levels, field operations and processing in general, and hydrographic project instructions. The basic requirements for each of these subjects can be found in the _Hydrographic Manual_.

We do have an excellent manual which has been accepted around the world. We are all proud of it and only with your help will it continue that way.

Thank you and are there any questions?

REFERENCES CITED

Umbach, M. J., 1976: _Hydrographic Manual_, Fourth Edition. U.S. Government Printing Office, Washington, D.C. (Stock No. 0-219-433), 330 pp.

DISCUSSION

Lt. Cdr. Floyd: It sounds like if I want my own copy, the best thing for me to do is purchase one from GPO and then it will be on record in my name and I will get the changes directly.

Mr. Ellis: That is correct.

Lt. Cdr. Floyd: How much does the _Hydrographic Manual_ cost?

Mr. Ellis: $14. That includes all the changes, forever and ever, as long as we have this edition. It's going to be quite an expense for NOS.

Mr. Barnes: Who do we see if we're not getting changes?

Mr. Ellis: Through the Requirements Branch (C351) of the Hydrographic Surveys Division. Are there any other questions? Thank you.

THE END PRODUCT--NAUTICAL CHARTS, BASIC ENGINEERING SURVEYS, OR BOTH?

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ABSTRACT. This paper reviews the pertinent National Ocean Survey (NOS) legislative mandate outlining the activities and products required of NOS and discusses the ramifications of this mandate. The relationships between these products are examined, and the fundamental reasons for each product's existence are reviewed. Although this paper does not propose to resolve any basic questions, it does attempt to clarify a number of issues and offers some positive recommendations. Pending additional comment and refinement, it is desired that administrative decisions be made accepting these recommendations.

INTRODUCTION

This paper will review the pertinent National Ocean Survey (NOS) legislative mandate outlining the activities and products required of NOS and will discuss the ramifications of this mandate. The relationships between these products will be examined and the fundamental reasons for each product's existence will be reviewed. An inspection of the accuracies required, the scales prescribed, and the relationship between the two will be made for each product. It has been through differences of opinion concerning these various relationships among products and between scale and accuracy that the impetus to develop this paper was first generated. It is only natural for program managers to promote their own product and to attempt to reduce the amount of extraneous effort to minimal levels. In recent years the restrictions on personnel ceilings and tightened budgets have become a reality managers must live with. If new programs are to be developed and promoted, there normally must be a corresponding reduction in activities and efforts which already exist. There are two ways in which this can be accomplished. Either present standards are maintained and the quantity of effort is reduced or the amount of work is kept at past levels with a reduction of data quality. Most differences of opinion as to future efforts are based on these three opinions: (1) introducing new products with a correspondingly reduced data quantity, (2) introducing new products with a correspondingly reduced data quality, or (3) maintaining the status quo. The preparation of this paper has been a concern of mine for some time. In June 1979, I circulated for comment a discussion of a portion of the subjects covered herein. The response was excellent and much of the material included here is responsive

to those comments. In all honesty I must confess to several changes of opinion since first studying the problems. As a result, this paper is probably not quite as controversial as it may have been if written 6 months or more ago; however, I do have some recommendations to propose that I hope will spur some activity.

THE NATIONAL OCEAN SURVEY'S MANDATE

On October 3, 1970, Presidential Reorganization Plan No. 4 of 1970 became effective, creating the National Oceanic and Atmospheric Administration and abolishing the Environmental Science Services Administration. Section 14 of U.S. Department of Commerce Order 25-5B reassigned to the National Ocean Survey the duties and functions of the former Coast and Geodetic Survey. This mandate includes the following functional responsibilities:

> The National Ocean Survey (NOS) shall provide charts for the safety of marine and air navigation; provide a basic network of geodetic control; provide basic data for engineering, scientific, commercial, industrial, and defense needs; and support the quest for more fundamental knowledge of our geophysical environment. In performance of these functions, it shall conduct surveys, investigations, analyses, and research; and disseminate data in the following fields: geodesy, hydrography, oceanography, seismology, gravity, geomagnetism and astronomy..

NOS responds to these responsibilities by producing (1) nautical charts, (2) bathymetric maps, (3) hydrographic sheets, and (4) topographic manuscripts. The nautical charts are composites of hydrographic sheets, topographic manuscripts, and other lesser inputs. The bathymetric map has a similar relationship to hydrography and topography. However, each of these four entities is important in its own right, and each has its unique uses.

The primary user of the nautical chart is the mariner. The largest single user is the U.S. Navy, but there is also substantial usage by commercial shipping, the fishing industry, and recreational boating. Those involved in engineering surveys frequently use nautical charts as the basic diagram in their studies.

Most of us are less familiar with the uses of the bathymetric map, but they are more numerous and diverse and generally science related. The maps are used in environmental impact statements in support of lease programs, determining potential hydrocarbon deposits, evaluating the topographic and geological detail of the sea floor, and studying sediment movement. The fishing industry finds the map useful in its pursuit of fish. Inshore planners use bathymetric maps to determine the quantity of material needing to be transported in dredging plans and beach sand replenishment projects. Coastal zone management personnel also use this product.

The primary use of the hydrographic sheet is to provide data for the nautical chart and bathymetric maps; however, these are not the only areas

that use these surveys. Coastal zone management programs are making increasing use of hydrographic surveys. Scientists studying such geographic phenomena as sand wave migration use the surveys, as do engineers planning underwater construction projects. Those in the fishing industry, if aware of the surveys, frequently make use of them.

Topographic manuscripts are primarily used in support of nautical charts and bathymetric maps. Recently, state and local governments have recognized the value of contemporary and historic topographic manuscripts in support of shoreline management programs. Within NOS, the new Coastal Hazards Mitigation Project Office utilizes these documents.

SCALE DETERMINATES

There are varying factors and degrees of documentation involved in determining the scale to be used under different circumstances for the four products. There are essentially no documented guidelines concerning scale selection for nautical charts. However, there are many considerations in selecting chart scale, particularly for large-scale charts. If a suite of charts is to be produced, a scale must be selected which is acceptable for the total area to be covered. For any specific area, factors such as topographic features, cultural details, traffic tonnage (and, to a lesser degree, volume), the existence of channel detail, etc., must be considered for adequate portrayal. In selecting a scale for harbors and approaches, one must consider ranges, overlaps, continuity for the mariner, landfalls, etc. Some charts are selected to include specific features such as the 200-mile limit. In all cases, however, the chart scale selected should ultimately best suit the needs of the mariner.

The scales of bathymetric maps are generally direct responses to the U.S. Geological Survey in support of their National Mapping Program. These scales are normally 1:100,000 and 1:250,000. Larger scale maps at 1:50,000, or multiples thereof, are used only for special maps. All bathymetric maps use metric depths.

The specified scales of hydrographic sheets are generally quite well documented. As a rule, the scale of the hydrographic sheet has been selected to be at least twice as large as the largest scale chart of the area. The NOS specifications as stated in the Hydrographic Manual (Umbach 1976) require that the basic scale for inshore surveys of waters less than 20 fathoms deep shall be 1:20,000 or larger. As the surveys proceed offshore, their scales decrease in multiples of the basic scale (i.e., 1:40,000 or 1:80,000). Surveys in harbors or other congested waterways are at scales of 1:10,000 or larger (i.e., 1:5,000 or 1:2,500), again in multiples of the basic scale. All of the NOS requirements for scale meet or exceed those recommended by the International Hydrographic Organization (IHO).

Even these scales are frequently exceeded (by larger scale surveys) due to a practical requirement for clarity in the final hydrographic sheet. The decision to exceed a specified survey scale is usually made by the hydrographic unit at the scene of the survey. This is often necessary since the

desirability of scale enlargement cannot be recognized in an office evaluation. Generally the scale is selected to portray the basic line spacing at an interval of 1 centimeter. Thus, in reality the primary driving force presently behind the scale of the hydrographic sheet is to achieve a readable presentation of soundings at the required line spacing. The impact of such "scales-for-presentation" is to place more stringent positioning requirements on control than would be necessary to support chart construction or to meet NOS or IHO standard scale specifications.

With only a few exceptions, the scale of the topographic manuscript is based on the scale of the corresponding hydrographic survey. Actually there are two different photographic scales involved in preparation of the manuscript. To prepare the shoreline to accompany a hydrographic survey generally requires a film scale no less than one-third that of the final manuscript. However, to identify the offshore features and navigation aids requires a film scale seldom to be of smaller scale than 1:20,000. Thus, the scale of the topography is as needed to accompany the hydrography and identify the offshore features. If only a revision shoreline is needed to update a nautical chart with no associated hydrographic survey, a smaller scale may be permissible than if hydrography is scheduled.

ACCURACY DETERMINATES

Thus far we have examined factors involving nautical charts, bathymetric maps, hydrographic surveys, and topographic manuscripts; however, the remainder of the paper will stress only the two basic field-produced products--hydrographic sheets and topographic manuscripts.

The required accuracy of a plotted position on a hydrographic sheet, as stated in both NOS and IHO specifications, is defined by the scale of the survey and the limitation of plottable accuracy. These documents both state that the accuracy or location relative to shore control shall seldom exceed 1.5 mm at the scale of the survey. "Seldom" in this case is not defined. Although somewhat beyond the scope of this paper, Capt. Wayne Mobley (1979) discusses this and other proposed accuracy standards for NOS in an unpublished paper that would be of interest to anyone involved in this area of concern. It soon becomes obvious that, with these guidelines, it is the scale of the sheet that drives the accuracy required of the hydrographic survey and little else. And as we have already seen, the force driving the scale in many cases is readable presentation of the sounding data.

The further one examines the problem of hydrographic accuracy, the more concerned one becomes with what accuracy we are actually achieving. Electronic control has provided a great deal of concern since its inception and shall undoubtedly continue to do so as we learn more about its properties. In a paper delivered at the 1st International Hydrographic Technical Conference in Ottawa, Canada, in 1979, Mr. J. G. Riemersma of the Netherlands recommended the use of redundant fix information as a means of increasing the confidence level of a given position.

Topographic manuscripts also define their accuracy requirements in terms of a relationship to scale. For shoreline manuscripts the plotted positions of control stations, landmarks, fixed aids to navigation, etc., shall not exceed 0.3 mm at the scale of the survey from the true ground positions. For photo-hydro stations and well-defined points of detail this variance is not to exceed 0.5 mm at the scale of the survey.

Whenever accuracy standards are mentioned, inevitably the U.S. National Map Accuracy Standards are mentioned. Interestingly, neither hydrographic sheets nor topographic manuscripts can fall under the requirements of these standards due to the lack of absolute verification, but then NOS has never presumed that these sheets and manuscripts did. Briefly, the U.S. National Map Accuracy Standards require that for maps of a scale greater than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 0.85 mm at the map scale. This applies to well-defined points only--those that are easily visible or recoverable on the ground such as control marks, road intersections, railroads, corners of large structures, or centers of small buildings. "Well-defined" is further categorized as capable of being plotted at an accuracy of 0.25 mm at the map scale. Obviously, these standards are not applicable to hydrographic surveys and only a few topographic manuscripts contain sufficiently numerous well-defined points to qualify. The standards continue to state that published maps meeting those accuracy standards should note in their legends that "This map complies with National Map Accuracy Standards." Inasmuch as neither hydrographic surveys nor topographic manuscripts contain this statement, NOS has never claimed to meet these standards on these products.

USER REQUIREMENTS

The scales of nautical charts and the bathymetric maps are responses to the needs of a maritime public, either implied or specific. However, it is far more difficult to distinguish a correlation between the scale of the hydrographic sheet (and correspondingly, the scale of the topographic manuscript) and any user demand or requirement. Rather, the survey scale, as we have seen, is based on a set of models determined to adequately account for distances offshore and the nature of the bottom. Realistically, it is based on a pleasing portrayal of the required sounding data. I am unaware of any regular public demand or interest in our survey scales. Those that do use the hydrographic sheet as a data source are more interested in accuracy (actually, they are more likely interested in data quantity) than in scale.

Let's open our eyes for just a moment. Totally digitized surveys are just barely over the horizon. The majority of future data users will have computer graphic capability. When these digitized surveys are played back on the user's equipment, that user will plot at the scale of specific usefulness to them. It is most unlikely that there will be any relationship to the original survey scale. Restated, the future user will be unconcerned with the acquisition scale of hydrographic data, only with its accuracy. At this point it should be noted that the NOS legislative mandate does not specify the format to be utilized in providing basic engineering or scientific data to the user.

RECOMMENDATIONS

With this discussed background in mind, I would like to offer a number of recommendations.

1. The one-to-one relationship between hydrographic sheets and topographic manuscripts should be continued with three exceptions. The Photogrammetric Division has stated that they can identify and position 95 percent of all offshore features and navigation aids at a scale of 1:20,000. Accepting this fact, film scale for topographic manuscripts need not be larger than 1:20,000. This statement does not apply to photo-hydro support data which still must be provided at the scale of the hydrographic sheet. In areas basically devoid of offshore features and navigation aids (i.e., much of the Gulf of Mexico), the Photogrammetric Division and the Hydrographic Surveys Division will discuss relaxation of the one-to-one scale relationship. It must be borne in mind that photogrammetry can achieve the same scale accuracy as a hydrographic survey at a scale one-fifth that of the survey. In those cases where manuscripts are compiled at the scale of a proposed hydrographic survey and that survey scale is subsequently increased, there will be no requirement to recompile the manuscript. An enlargement of the appropriate manuscript will be provided for shoreline on the hydrographic sheet. In this or in any other case (such as a blowup of a chart shoreline) where shoreline depicted on hydrographic sheets is enlarged from another printed source, it shall be labeled "Shoreline on this survey is an enlargement of a 1:__________-scale topographic manuscript, nautical chart, etc." This annotation is particularly important when one considers that normally shoreline from an enlargement is shown on a hydrographic sheet in brown ink to denote that fact. Of course, the brown ink reproduces as black and the distinguishing aspect of its presentation is lost to the user unless annotated.

2. The digitized survey will free the hydrographic sheet from the previous scale restraints which existed with the plotted sheet. Even without this product, the stress placed by NOS and IHO on the survey scale is questionable. It becomes even more debatable when the factors determining the scale have been reviewed. I propose that the emphasis on scale be diminished and that a new emphasis on accuracy be stressed. We would not disregard line spacing and scale of survey, but would add the new, separate requirement of accuracy to the survey. The requirement for accuracy could be based on a tolerance stated in meters for a given confidence level. Accuracy could be based on distance offshore, depth of water, or some other criteria and could be based on the anticipated use of the data. However, by relating the survey to accuracy, we would more appropriately respond to the true user need and correct a serious deficiency or, at the very least, a source of considerable contradiction.

3. The production of archive quality hydrographic sheets and topographic manuscripts is a labor intensive and time-consuming process with much of the effort going into the cosmetic side of the product. It is doubtful that NOS can long continue to afford the scarce personnel resources required to produce such surveys and manuscripts, particularly with the advent of the digitized file.

SUMMARY

In this paper we have reviewed the relationships between the facets of nautical charts, bathymetric maps, hydrographic sheets, and topographic manuscripts and recommended some actions. Pending additional comment, I would like to see some positive decisions made on these recommendations.

In closing I would like to leave you with this analogy which rather nicely illustrates the relationship between the nautical chart or bathymetric map and the hydrographic sheet or topographic manuscript. This illustration is attributable to Commander Don Nortrup.

A nautical chart is essentially a graphical abstract of the surveyor's work. It might be compared to a literary abstract of a classic novel. A student, cramming for an exam, would probably find the literary abstract more valuable to the immediate needs, i.e., passing the exam, than the novel itself. It can hardly be concluded that, because of application, the abstract is the product of the author's efforts. The abstract is clearly the product of a hack while the product of the author is the novel itself. In the field of hydrography the nautical chart is the product of the cartographer. The chart meets the needs of the navigator like the literary abstract meets the needs of the student. The product of the hydrographic surveying process is clearly the survey sheet itself and anyone needing "the whole story" will have to obtain the survey sheet like the serious reader obtains the novel.

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DISCUSSION

Mr. Monteith: Don, you might mention that NOS also has a responsibility, in addition to the products that you detailed, of publishing fishing obstruction charts, and although not funded, this could be a rather large program in the future.

Lt. Cdr. Suloff: I didn't mean to infer by the four products that I mentioned that those were the only four products of NOS. They were the four products that I was examining within the scope of this paper.

Lt. Cdr. Floyd: You said that accuracy depends on the scale, and the scale depends on the line spacing. But you didn't carry it a step further. The line spacing depends on navigational considerations, such as depth and distance offshore, so maybe the way to solve this problem is to define more rigidly what the line spacing ought to be. This would carry all the way through to your accuracy requirements.

Lt. Cdr. Suloff: What you say is correct to a degree, but the requirements for line spacing are rigidly stated within the Hydrographic Manual. The case we come upon frequently is one where a great amount of development hydrography is necessary, requiring the plotting of the data at a larger scale than would be otherwise required to portray the standard line spacing. Thus, the larger scale survey is needed only to portray data not required under the basic rules for line spacing, but rather required to locate and determine a feature's least depth. However, as we have discussed, the accuracies required for the hydrographic data are tied to the scale of the survey. In the case of these developments we are seeking additional data, not more accurate data. Yet the final effect of the increased sheet scale is a more rigid accuracy requirement and its corresponding additional demand on the survey unit. These situations, where accuracy requirements more rigid than those actually needed are imposed due to an increase in survey scale, are the situations I would hope to alleviate by specifying accuracy requirements as a separate entity from sheet scale.

Cdr. Pfeifer: You had something to say about the users of the products or at least for the wet products which you present in your paper. Have you had any chance to examine the users of the products which we put out which are not ocean-oriented in the geodesy and aeronautical charting discipline?

Lt. Cdr. Suloff: No, that was beyond the scope of the paper, and I didn't try.

Mr. Moore: In my mind and the minds of many people, when you mention accuracy, that is where the object is, and no question about it. There's a difference between the accuracy and precision which was pointed out in one of the previous sessions. Somebody could be using a 24-inch ruler and it would be very precise to take hundreds of measurements and say this is where something is. But if the ruler is wrong, then the accuracy is wrong.

Not only should you consider the standard deviation, which is the RMS deviation from the mean, but also the mean. This gives you what's called an RMS value, which includes the average value plus the standard deviation and effectively that's the hypotenuse of that triangle.

I would therefore caution you in the use of the term "accuracy," because all instruments are different and there's an awful lot involved in hydrography. If you use the term "accuracy," then either the chart or someplace similar should precisely define what is really meant by that term.

SPECIAL REPORT - LAUNCH WIRE DRAG*

Lt. Cdr. Max M. Ethridge
NOAA Ship WHITING

ABSTRACT. The equipment, field procedures, and processing of a launch wire-drag configuration are discussed. The methods and equipment used were scaled down from specifications in the Wire Drag Manual for ship wire drag.

LAUNCH WIRE-DRAG GEAR

Reference. The equipment, field procedures, and processing techniques used in this launch wire-drag arrangement were adopted almost entirely from the Wire Drag Manual (Ulm 1959). The methods and equipment used here are a scaled down version of those described in the Wire Drag Manual for ship wire drag.

Equipment. (See fig. 1.) The following equipment was used: two Jensen launches (one acting as guide vessel and one as end vessel), one Monark skiff, tester (10-foot pole and line) with grease mixture, two 150-foot towlines, two spherical metal buoys each about 3 feet in diameter, two lead weights (approximately 50 pounds each), two upright lines (one for each buoy), five 50-foot sections of 3/16-inch ground wire and four toggles (floats which snap on the ground wire).

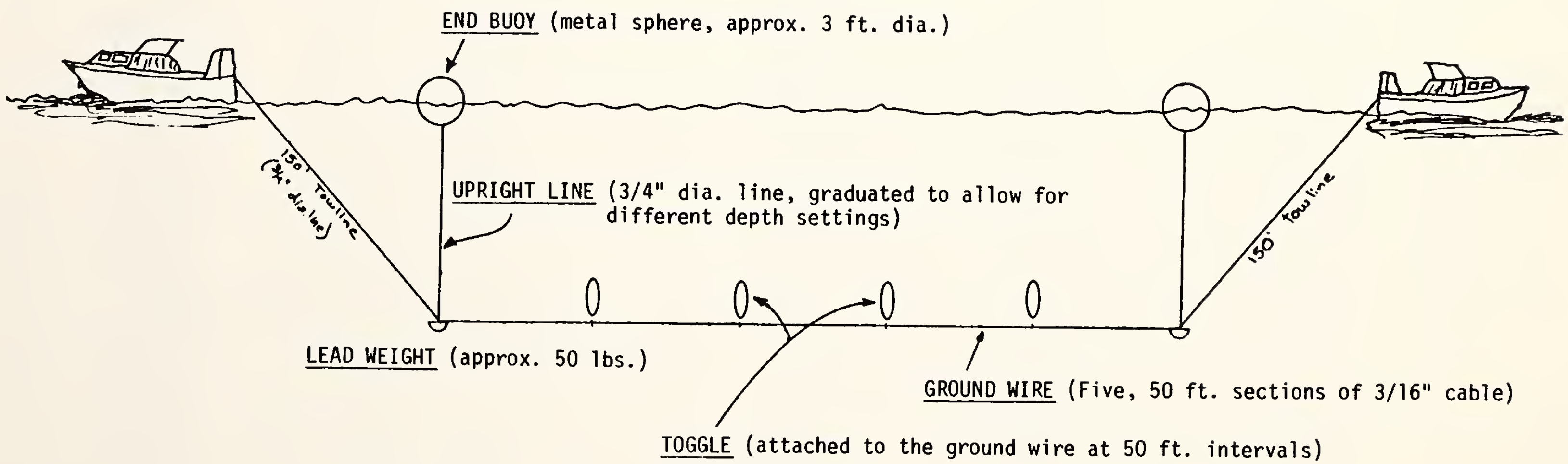
Personnel. Five people were used in the guide vessel, four people in the end vessel, and two people in the tester boat (Monark).

FIELD PROCEDURES

1. Determining Drag Depth. In order to determine at what depth the upright lines should be set (i.e., the depth of the drag), it is necessary to know the shoalest bottom depth in the drag strip, the anticipated lift, and the height of tide during dragging operations. The shoalest depth is obtained from previous hydrography; the anticipated lift is predicted based on previous experience with the wire drag under similar conditions; the predicted tides are obtained from the Tide Tables. The length of the upright lines are set before the wire drag is deployed.

2. Determining the Path of the Drag. The area which is to be cleared by the drag strip is determined by establishing the direction and effective width of the drag strips. The direction of the drag is generally chosen so as to be parallel with the direction of the current in the area. On investigation item three (for example) the drag was run both due north and due south.

*This paper was not presented at the conference, but because of its timeliness, it has been included in these proceedings.



NOTE: All connections between adjoining sections of ground wire, ground wire and towline, upright line and ground wire, lead weights and ground wire, and toggles to ground wire should be made with shackles and swivels.

Figure 1.--Launch wire drag, NOAA Ship WHITING.

The effective width of the drag is determined by taking some percentage of the total length of the drag so as to allow a normal bight (or catenary) to form between the two towing vessels. In this particular case (for item number three) an effective width of 110 meters between towing vessels was utilized. Therefore, the path of the drag was either a course 000^{o}T or 180^{o}T depending on which direction the drag was proceeding through the 100-meter radius circle about the reported position of the obstruction. Also, the two parallel paths of the towing vessels were separated by 110 meters (the effective width of the drag).

3. Setting the Drag. The time on the two launch computer clocks was synchronized, the line (towpath) which each launch was to steer for the drag strip was dialed into the launch computer, and the coxswain's steering needle was activated. The guide vessel went to a location midway between the two towpaths and well outside the 100-meter radius circle. The end vessel passed by and handed the end of the wire to the guide vessel. The ground wire was connected, and each launch proceeded slowly on a course toward its respective towpath while paying out its half of the drag. When all the drag had been deployed and the towlines were set, the two launches were each situated near its towpath, approximately abeam of each other and 110 meters apart.

4. Towing the Drag. The wire drag was towed at idle speed (dead slow) by the two Jensen launches, and simultaneous fixes of the two launches' positions were taken at 2-minute intervals. The launch coxswains each steered a needle to maintain their launch on the predetermined towpath. The guide vessel maintained constant engine RPM's while the end vessel either increased or reduced RPM's to maintain abeam configuration with the guide vessel. It should be emphasized that a constant force must be exerted upon the drag at all times in order to have consistent lift tests. Large changes in RPM's or course by either towing vessel will result in a lift change. Also, if for any reason either towing vessel comes to an all stop, the toggles (floats) which are attached to the ground wire will float to the surface as the drag becomes slack.

Drag strips were laid out to clear the 100-meter radius circle in two directions (south to north and north to south). When the end of a strip was reached, the direction of the drag was easily reversed by having the launches simultaneously come about on the outboard side of the drag and steer the reciprocal of their original course. When reversing the drag, it is essential that the reciprocal course be steered long enough for the drag to develop a normal bight before the tow vessels move inside the 100-meter radius circle or testing of the drag commences.

5. Testing the Drag. The determination of the actual depth of the ground wire below the water's surface while the wire drag is under tow constitutes a very important factor in successful wire drag. Each drag strip which passed through the 100-meter radius circle was tested twice by the Monark, which acted as the tester boat. These tests were made by lowering a 1.5-inch diameter pipe coated with a mixture of grease and colored powder in front of the wire's path. The pipe was supported vertically from a line graduated in feet and set to allow the lower end of the pipe to extend 2.0 feet below the depth for which the drag had been set. When the wire drag

passes the spot where the tester is located, the bottom wire makes contact with the pipe and scrapes off a trail of grease extending from the initial point of contact to the lower end of the pipe. After the drag has passed by the tester, the tester is recovered and the distance that the initial point of contact between the wire and the pipe (as indicated by the highest point of the scrape mark on the pipe) lies above the zero mark on the pipe is determined (the zero mark on the pipe is located 2 feet above the bottom end of the pipe). Thus, a scrape mark beginning 3.0 feet above the end of the pipe and extending along the pipe to its lower end would be recorded as 1.0-foot lift. Likewise a scrape mark beginning 1.0 foot from the end of the pipe and extending the full 1 foot to the end of the pipe would be recorded as 1.0-foot sag. (Note: When calculating the effective depth for drag strips, all tests which indicate sag are treated as 0.0-foot lift.)

When the wire drag was towing properly and all the components of the drag (i.e., weights, upright lines, towlines, toggles, etc.) were set correctly, the tests for lift ranged from 1.0-foot lift to 1.0-foot sag. At other times when weights were missing or upright lines were set too deep, the tests ranged from 4.0-foot lift to 2.5-foot sag, respectively, and indicated that something was wrong with the drag. (Note: Under normal circumstances for shallow water, wire-drag lifts would be expected to fall within a range of about 2.0-foot lift to 1.5-foot sag.)

Obviously, the lift (or sag) at the bottom wire figures significantly into the success of a wire-drag operation. However, lifts can be very sensitive and difficult to control. They are a function of the drag's towing speed, speed and direction of currents, length of towline, depth of drag, size of weights, buoyancy of the toggles on the bottom wire, size of the bottom wire, and the percentage of the drag length used as the effective width.

6. Effective Width and Overlap. As stated earlier, the effective width used for the investigation of item number three was 110 meters or about 360 feet. Since the total length of the drag including towlines was 150 + 250 + 150 = 550 feet, 360 feet represents about 66 percent of the total length of the drag. This percentage for effective width seemed to work well because the bight of the drag (catenary of the wire between towing vessels) looked good, and there was enough slack in the drag to allow each launch to maneuver without being pulled by the wire. In general, it is recommended that 65 to 70 percent of the total drag be used as the effective width for small wire drags, and as the length of the drag increases, 70 to 75 percent may be used as the effective width. (Note: In classical ship wire drag the effective width is measured between end buoys; i.e., the lengths of the towlines are not figured into the effective width calculations. However, in this launch wire-drag arrangement the lengths of the towlines were included because of the difficulty in positioning the end buoys in the field.)

No attempt was made to take fixes on the end buoys as the launches were maintained on their respective towpaths 110 meters apart. Instead, during processing the simultaneous positions of the launches taken at 2-minute intervals were plotted and a normal bight was placed between the two launch positions. The positions of the end buoys were marked on the bight and transferred to the area and depth sheet at each fix (see the section on

processing). The end buoy positions were connected with straight lines between successive fixes, and only the area lying between the two end buoys was claimed as area dragged. Thus, the area dragged by the towline running from the launch to the end buoy was not claimed. Fifty percent overlap between adjoining drag strips was utilized to (1) make up for the area dragged by the sloping towline but not claimed and (2) allow for steering problems which result in deviations from the desired line to be made good. Thus, when it was desired to move the drag to the adjoining strip, each launch moved their line 55 meters, and a new strip was begun.

7. Hangs--Getting Their Position and Clearing the Wire. When the drag hangs on an object, the forward progress of the launches stops, and the wire becomes tight. The drag can be cleared from the hang by either of two methods. (1) If it is desired to get a position on the hang, the best procedure is to have both launches back down toward the wire while pulling the wire aboard. While this is being done, it is important to maintain proper tension on the wire to prevent it from slipping off the hang. Eventually, the wire will lead almost straight up and down from the stern of the launch to the object hung. At this time a detached position should be taken to determine the position of the hang. Also, if the tester boat (Monark in this case) is equipped with a fathometer, a good trace over the hang can sometimes be obtained by using the angle of the wire to locate the immediate area of the hang. (A marker buoy can also be deployed to mark the position of the hang for future use.) When both launches are situated almost directly over the hang, the wire can usually be pulled upward and off the obstruction. Care should be taken when maneuvering on the hang so as not to allow the two launches to cross over each other's wire. Besides risking getting the wire caught in the launches' propeller or rudder, this allows the wire to be wrapped around the hang and sometimes even to be tied in knots. (2) If a position has been obtained on the hang and the wire needs only to be cleared, the simplest procedure is to reverse the drag and pull the wire off the hang. As stated earlier this is accomplished by having the launches simultaneously come about and steer the reciprocal course.

8. Setting Drag Strips to Clear Known Obstructions. Before the drag can be designed to clear an obstruction, it is necessary to have an estimate of the obstruction's least depth (divers are very effective in obtaining the least depth of an obstruction and/or determining how far it projects off the bottom). If a reliable estimate of the least depth is not available, the depth at which to set the clearing drag becomes a guessing game and results in a trial and error procedure. The clearing drag strips, which were used to clear the two hangs encountered while working item number three, were set to clear the top of the obstructions to within 2 feet. For example, if the estimated least depth of an obstruction was 12.0 feet, it should be cleared to an effective depth of at least 10.0 feet. Also, all hangs were cleared in two directions to ensure that the wire did not slip over a sloping object. NOTE: When wire drag strips are set to clear an area (as opposed to a hang), they should be designed to obtain an effective depth within 2.0 feet of the bottom. Obviously, it is very important to test the drag and obtain accurate measurements of lift (or sag) for all clearing strips.

PROCESSING LAUNCH WIRE-DRAG DATA

The launch wire-drag data were rough plotted on the ship at the end of the day's dragging operation and an area and depth (A&D) sheet was compiled. The area of coverage was determined as follows: (1) The simultaneous positions of the guide and end vessels were plotted for each 2-minute fix. (2) A bight made from a flexible plastic template, and scaled to the exact length of the drag at the corresponding scale of the rough sheet (1:1,250 was used for item number three), was situated between the two launch positions. (3) The path of each end buoy was determined from the bight and only the area between the paths of the two end buoys was claimed as cleared by wire drag (see the last paragraph of discussion on effective width and overlap). The effective depth of the drag was determined by the following relationship: effective depth equals drag depth minus lift minus height of tide above MLW. All detached positions were plotted on the rough sheet (i.e., positions of hangs). The end product of wire-drag data reduction is a plot showing (1) the positions of the guide vessel and end vessel at each 2-minute fix, (2) the area cleared by wire drag, (3) the effective depth of each area cleared by wire drag, and (4) the position of each hang. For the purposes of clarity, a separate plot was made for all north to south drag strips and also for all south to north drag strips.

Appropriate notes describing conditions occurring in the field which affect the wire drag are recorded in the sounding volumes. These notes should be taken into consideration when processing the data.

RECOMMENDATIONS

Experience with this launch wire-drag arrangement suggests the following: (1) Due to the nature of the operation (i.e., using small boats and working with gear over the side), it is recommended that launch wire drag be conducted only under favorable weather conditions (i.e., calm seas, light winds, warm temperature, and currents less than 1 knot). (2) It is highly recommended that divers be used in conjunction with the wire-drag operation. When a hang is encountered, divers should be available to swim down the wire and investigate the hang. Divers are ideal for determining the nature, disposition, and least depth of an obstruction and also for clearing the wire from the hang. If no divers are available, fathometer searches must be used for determining the least depth. This technique is hit or miss (the Ross fathometers are narrow beam) and is neither reliable nor efficient. (3) It is recommended that launch wire drag be utilized only when it is anticipated that other more efficient techniques will not be effective in locating or disproving items. This is suggested because of the large number of personnel and the amount of equipment (10 men, 2 launches, and 1 skiff) required to conduct the operation. The amount of time required to conduct launch wire drag should also be considered. It is not uncommon to spend 3 days clearing one 100-meter radius circle in both directions to an acceptable effective depth. Such an effort represents the effort of 10 people for 3 days, 6 launch-days, and 3 skiff-days. (4) The launch wire-drag arrangement described here appears to have reasonable potential for working items in shallow water. However, more experience with this technique is needed before it can be considered as completely reliable.

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CLOSING REMARKS

Capt. Roger F. Lanier
Associate Director
Office of Marine Surveys and Maps
National Ocean Survey, NOAA

Thank you very much, Dale. Ladies and gentlemen, I'm glad to be here. I'm sorry I wasn't able to be here more this week. I had expected to, but for reasons that I couldn't control I couldn't be here a good part of the time.

I do expect that most of you, after spending this week here, aren't very anxious to listen to me tell you at length what's gone on here. So I'll try to be as brief as I can.

I have enjoyed very much the presentations that I did hear. They were very well done, timely, and informative.

Thank you all for coming to the conference. I believe that most of us were somewhat surprised at the number of attendees, but were pleased to see all of you. As most of you know, this is the first time we've invited anyone outside of NOAA, and we are pleased to see our friends from the Canadian Hydrographic Service, the Defense Mapping Agency, and the Navy. We want to thank you for your participation, and we hope you found this conference beneficial.

Speaking for NOS, I assure you that our close working relationships are of great benefit, and we look forward to working with you in the future. As an example, Capt. Posey and some of his charting experts spent a day this week in Ottawa, resolving some discrepancies in charts of the St. Lawrence Seaway.

On behalf of NOS and the Conference Committee, our sincere thanks to each of the speakers for your excellent response to the request for papers. It is quite evident from your presentations that you have worked hard to make a worthwhile contribution and I believe you succeeded. Thank you very much.

Finally, I'd like to thank the hard-working Conference Planning Committee for organizing the conference and keeping it on schedule. They did a great job, and I'd like to ask all of them to stand.

Dale Westbrook, Chairman; Bill Monteith, Don Engle, John Perrow, Don Spillman, and Joyce Hopkins. How about a round of applause?

I understand the conference proceedings will be published as soon as possible, and each of you who has registered will be sent a copy.

As most of you know, this is an annual conference which implies, of course, there'll be one next year. It's become customary to rotate them between the marine centers and Headquarters. Next year's conference will be

held at our Atlantic Marine Center in Norfolk, Va. Admiral Houlder, the Director of the Marine Center, has told me that they are looking forward to holding it there.

That brings me to one last point--the conference itself. They started as small and rather informal meetings, as Chuck Ellis mentioned a little bit ago, less than 20 people in their conference room. Each year, I think they have gotten a little larger and probably more formal. That is fine, as long as they don't get out of hand, and they do what they're intended to do.

I hasten to add that I don't believe the purpose should be cast in concrete, but my personal feeling is that they shouldn't become too large and formal, where a frank and open discussion is inhibited. I don't think that's happened here, from the comments I've heard. I understand that a questionnaire on this conference will be distributed to each of you. I'd like to ask each of you to give serious thought to your answers, as to whether it is meeting your requirements as well as it might. Your frank opinions and suggestions are needed.

Again, I want to thank all of you for attending, and I want to wish you a safe and pleasant trip home. I understand that some of you going to Seattle might need some skis, or snowshoes, or a boat to get home from Sea-Tac. Thank you very much.

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